Contents #111

For subscription details etc. see inside back cover.
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Editorial #111

Farewell to Alex Johnstone

Alex Johnstone, pioneer of chemical education, has died at the age of 87 after making many contributions to chemical education research (CER) over many decades. He founded a very successful research school in CER at the University of Glasgow, later continued by his student Dr Norman Reid. An appreciation can be found on p.53 by Bob Worley, who highlights Johnstone's triangle and his work on cognitive overload. I met him several times at conferences and his talks were always inspiring and challenging.

National STEM policy published

The end of 2017 saw the publication of a major development plan for STEM Education, following on from the STEM Education Review Group report and the subsequent consultation. The government has produced a 10 year policy report and a 2 year action plan. The proposed actions are very ambitious but there are signs that the government is taking STEM education seriously and is actually going to do something. You can find information on p.4 and p. 12. It is well worth reading both reports as they have implications for science teachers and the ISTA, and for science teacher providers and science education researchers. It is good to see that this year's SMEC conference in DCU/St. Patrick's College will deal with science policy.

Is there a real shortage or not?

In December 2017 the papers were full of dire warnings about teacher shortages in specific subjects, and Physics was mentioned. (See p.6)
There is a tendency to only focus on science teachers produced through the consecutive route (PME) and ignore the greater number of science teachers produced through the various concurrent programmes. So instead of only 6 Physics teachers being produced a year we are talking of maybe 30-40 in total. There are many more Biology teachers in the system and being trained than in Chemistry and Physics, which partly explains the dominance of Biology as a LC science subject. There may be a real shortage of Physics and Chemistry teachers when principals go looking for teachers, partly due to the relatively small supply but mainly because science teachers leave the profession or leave the country to find work. Redressing the pay differential for new teachers and providing more opportunities for full-time posts are probably more important factors than the number of teachers in training. Maybe Ireland should also consider further in-service courses for Biology teachers to help them teach Chemistry and Physics, similar to the one being done for out-of-field Mathematics teachers and teh ones that were run a few years ago under the auspices of the RSC.

IYPT: advance notice

2019 has been designated by the UN, IUPAC and UNESCO as the International Year of the Periodic Table, marking 150 years since Dimitri Mendeleev proposed his version (see p. 61).This is a great opportunity to promote and publicise chemistry as the Periodic Table is a familiar icon. I hope that we will be able to have a number of events and activities in Ireland during 2019 to mark the year. Why not think what you could do in your school to mark IYPT. There are lots of resources available – books, posters, T shirts etc.

Peter E. Childs
Hon. Editor

In this issue #111:

The main focus of this issue is the Proceedings of ChemEd-Ireland, held in October 2017 in the University of Limerick. The theme was 'Chemistry and Society' and there were some very interesting talks and workshops. In this issue we include the written versions of the talks by Professor John Sodeau (UCC) on climate change (p. 15), Professor William Reville on embedding science in society (with some controversial views on inquiry-based learning) (p. 23), Dr Stephen Ashworth's demonstration lecture on Kitchen Chemistry (p. 26) and Dr Micheál Scanlon's fascinating lecture on photoelectrochemistry (p. 35).

Adrian Ryder's series on 'Chemists you should know' continues with Ernest Rutherford (p. 48), who was really a physicist but won the Nobel Prize for Chemistry and features in every chemistry course.

A few years back two final year students in UL did research projects to answer the question: 'What makes a successful chemistry school?' Why do similar schools in intake, location etc. vary widely in their ability to encourage students to take LC Chemistry? Their findings are worth publicising and can be found on p.43.

The STEM policy statements feature in the Education News and Views Section and you should download and study the full documents.

Chemistry in Action! is now available online.

The current issue and previous issues can be accessed by going online to www.cheminaction.com

Also available on the website are electronic copies of the following Transition Year modules:

- Forensic Science
- Environmental Science
- Food Science
- Issues in Science
- Science and Medicine
- Science of Survival

Copies of various posters are also available.

You can also sign up to our emailing list to receive a copy of the most up-to-date issue by email. (Contact Marie Walsh at **marie.walsh@eircom.net**).

The web editor is Maria Sheehan and she can be contacted at: **mariasheehan400@gmail.com** if you have queries.

You can also access CinA! On the ISTA website.

We have discontinued sending hard copies to all interested teachers mainly due to the cost of postage. The electronic copy is available free-of-charge and a limited number of hard copies are being printed for libraries and our sponsors. The idea is to give tham out at conferences (ISTA and ChemEd-Ireland). If you want a hard copy please contact peter.childs@ul.ie and check availability before ordering at €5 per copy.

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Education News and Views

The Editor welcomes contributions and news of interest to chemistry teachers in this section.

2019 Year of the Periodic Table

2019 has been designated by the International Union of Pure and Applied Chemistry (IUPAC) as the International Year of the Periodic Table of the Elements (IYPT), in conjunction with UNESCO. 2019 marks the 150th anniversary of Dmitry Mendeleev's Periodic Table. The year also marks the 190th anniversary of Dobereiner's triads, a precursor of the Periodic Table, Antoine Lavoisier's listing of 33 elements in 1789, and the discovery of phosphorus in 1669.

"*As the global organization that provides objective scientific expertise and develops the essential tools for the application and communication of chemical knowledge for the benefit of humankind, the International Union of Pure and Applied Chemistry is pleased and honoured to make this announcement concerning the International Year of the Periodic Table of Chemical Elements*" said IUPAC President, Professor Natalia Tarasova.

2019 also marks the 100th anniversary of IUPAC, founded in 1919.

The IYPT will be used by UNESCO's International Basic Sciences Programme to promote international co-operation in the basic sciences for sustainable development. A UNESCO Global Microscience Experiments Project will also be dedicated to the periodic table. Microscience is an educational initiative that provides low-cost experimental equipment to primary and secondary school pupils – and university students in some countries.

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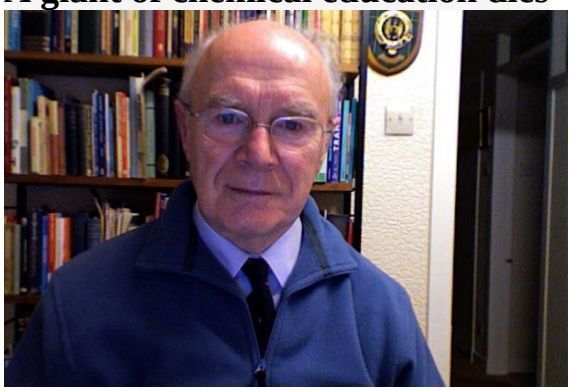
A giant of chemical education dies



There can be few chemistry teachers or chemical educators who have not heard of Professor Alex Johnstone, University of Glasgow. Alex Johnstone died on 1st December 2017 aged 87. He was variously chemistry teacher, university lecturer, chemistry education researcher and conference speaker, and had a major effect on the way chemistry was taught from the 1980s onwards and had a profound influence on the development of chemistry education research. An appreciation can be found on p. 53. His sons wrote a lovely tribute in *The Scotsman* at https://www.scotsman.com/news/obituaries/obituary-prof-alex-johnstone-academic-and-author-in-chemistry-1-4642975

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STEM education aim: to be the best in Europe

The STEM Education Review Group Report was published in November 2016 (https://www.education.ie/en/Publications/Education-Reports/STEM-Education-in-the-Irish-School-System.pdf). A consultation was then called on this report and a consultation meeting was held in June 2017, and based on submissions and an online consultation, and a summary report was published (https://www.education.ie/en/The-Education-System/STEM-Education-Policy/stem-education-consultation-report-2017.pdf).

This has now led in Nov. 2017 to the publication of a Policy Statement 2017-2026 (https://www.education.ie/en/The-Education-System/STEM-Education-Policy/stem-education-policy-statement-2017-2026-.pdf) and an Implementation Plan 2017-2019 (https://www.education.ie/en/The-Education-System/STEM-Education-Policy/stem-education-implementation-plan-2017-2019-.pdf).

When the new 10 year STEM Policy plan was launched on Nov. 27th 2017, the Department of Education issued the following press release:

Targeted Measures for Girls & Upskilling for Teachers

STEM in Pre-school Settings, Schools & More Information on STEM Careers

The Minister for Education and Skills, Richard Bruton, T.D. today launched his Department's STEM Education Policy Statement 2017-2026 and Implementation Plan 2017-2019. In line with

our objective to be the best in Europe, the plan being published today sets out the Minister's intention to make Ireland a European leader in STEM education by 2026.

We are undergoing a technological revolution globally. If Ireland is to be at the forefront of this transformation, we must be a leader in nurturing, developing and deploying STEM talent. This Policy Statement focuses on the many strengths in Science, Technology, Engineering and Mathematics education in Ireland, while providing a roadmap to address the areas for development.

Key ambitions include:

- Increase by 20% the total students taking Chemistry, Physics, Technology and Engineering for Leaving Certificate
- Increase by 40% the number of females taking STEM subjects for Leaving Certificate
- Increase participation in out-of-school STEM learning opportunities and STEM career activities
- Introduce a new primary maths curriculum, which will include creative and computational thinking and coding
- Accelerate the introduction of Computer Science at Leaving Certificate, with implementation brought forward to September 2018
- Introduction of new Junior Cycle Mathematics and Technology curricula
- Teachers will use a cross-disciplinary approach to incorporating STEM across all subjects
- Enhance STEM teaching, learning and assessment practices in early years settings
- Close the gap in achievement in STEM disciplines between students in DEIS schools and students in all schools significantly
- Ensure that all schools, learners and parents have access to high quality information on the diversity of STEM careers
- Build robust and sustainable partnerships between schools, business and industry, public sector bodies, research organisations, further and higher-level institutions and the Arts

Achieving our goals will require a significant step-up in support to teachers and school leaders and encouragement of innovation in teaching methods.
Actions to deliver on these ambitions will be included in our annual programme under the Action Plan for Education and their impact will be reported on.

Speaking at the Launch, Minister Bruton said:
"I have set the ambition to make Ireland's education and training service the best in Europe by 2026. We are living in a rapidly changing world and key to delivering on our ambition to be the best will be the ability of our education system to adapt to a transformed economy and society. Our children must be equipped with the necessary analytical, creativity and critical thinking skills to thrive in such an environment.
"That is why, during my time as Minister, I have prioritised the teaching and learning of STEM subjects. This Plan sets out how we will make Ireland a leader in the provision of STEM education.
"There is a significant gender gap between the number of males and females studying STEM. In this plan I've put an increased focus on encouraging traditionally underrepresented groups, such as females, to participate in STEM activities. We are increasing links between the education system and industry and putting in place supports to ensure our teachers feel confident to embrace STEM, in curricular, co-curricular and out-of-classroom settings.
"Curricular reform is vital. We are accelerating the implementation of the new Leaving Certificate Computer Science subject for example, and introducing a new primary Maths curriculum, which for the first time will include elements of coding and computational thinking.
"I have put together a 2 year Implementation Plan which sets out our annual targets to ensure we can meet our ambitions. I look forward to seeing our progress, in this important and exciting area."
The Minister thanked the members of the STEM Education Steering Group, the chairperson of which was Gary Ó Donnchadha, and the staff and pupils of St Clare's Primary School where the launch was held.
(https://www.education.ie/en/Press-Events/Press-Releases/2017-Press-Releases/PR17-11-27.html)

The best for STEM education in Europe

These are important policy statements and will dictate, if properly implemented, the coruse of STEM education in Ireland in the next decade.

They need thorough discussion by all interested parties and stakeholders – ISTA, IASEL (science teacher providers), third level institutions and industry. An interesting back-drop to these reports was the concurrent discussion of teacher shortages in specific areas, including science and maths. Without enough qualified teachers in relevant areas, it will not be possible to fulfil these objectives for STEM education. The discussion in the press on teacher shortages was on schools dropping specific subjects where there are teacher shortages, rather than on expanding provision.

Only six graduates in training to be physics teachers

Shortage of teachers in key subjects threatens to derail Government's Stem strategy

Irish Times 28/11/17

A shortage of teachers?

The newspaper headlines in November 2017 trumpeted: 'Only 6 physics teachers in training'. Read the small print and it was really 'only 6 physics teachers on the 2 year PME courses'. Once again the discussion of the provision of science teachers ignores the major contribution of the consecutive courses in science teacher education. Several institutions – St. Angela's, Sligo, UL, DCU, NIUM, UCD, UCC – produce science teachers by a concurrent route, including significant numbers in the physical sciences – physics and chemistry. UL alone has 20-30 students graduating each year who are qualified to teach Physics. It is still true that the majority of science teachers being produced are qualified to teach biology and the science teaching profession is predominantly biologists, but the situation is not as dire as was said. The real issue is of course how many physics teachers are needed each year to fill vacancies? No-one seems to know the answer to that, or in any other shortage area.

There are two problems. One is the problem of teacher supply: how many teachers are being produced each year in specific areas like chemistry or physics?; how long and by what route are they produced?; is there any planning or quotas in relation to needs? This is a problem of supply. There are several routes for producing science teachers at present: taking 4 years (concurrent), 5 years (concurrent), 6 years (4 years degree plus 2 years PME). The 4 year route produces teachers with a bachelor's degree and the other routes teachers with a master's degree. Fees are only paid for 4 years. Each college sets its own quotas of students and there is no overall planning. The numbers taking science in the PME courses depends on demand from other graduates and there are no quotas for shortage subjects. There is no overall national planning on teacher supply and demand in any subject. As in other areas, such a system produces a glut in some areas and famine in others.

The second problem is that of filling vacant posts and particularly providing substitute cover. This is a problem of availability. Firstly, how many permanent/temporary fulltime/part-time jobs are available each year in relation to the output of teachers? Secondly, how many qualified teachers are available on the market to take up such posts? Thirdly, are the pay and employment conditions attractive to a new graduate compared to alternatives e.g. going abroad to teach and going into other careers? The problem of young teachers in regard to pay and lack of opportunity for fulltime employment (never mind permanent jobs) has been well rehearsed. A succession of short, poorly paid, jobs in different schools is never going to be attractive. Teaching in Dublin has its own problem in relation to transport and housing costs.

The problem with getting substitute teachers at short notice to fill gaps is even more problematical: it presupposes a pool of qualified but unemployed teachers waiting to be called to fill a short-term gap. Anyone of any initiative or ability, if not already in a longer-term position in Ireland, will have already left the country or changed careers.

A number of things need to be done, in my opinion. These apply to both physics and chemistry teachers.

Firstly, do some long-term planning in relation to teacher needs in different subjects and then give incentives or have quotas to meet those needs. In reality this means in the PME courses, which are dominated by arts subjects due to the way places are allocated. It is not a problem with the concurrent degrees where one knows from year to year how many science teachers will enter the various courses.

Secondly, teaching needs to be made more attractive by removing the pay differential for new entrants and by making more long-term permanent appointments rather than temporary short-term ones. It currently takes years before a new teacher, in most cases, is made permanent.
Thirdly, if there are specific shortages in certain areas then these may need to be addressed by specific, short-term incentives e.g. no fees, until the shortage is eased.
Fourthly, provide opportunities for out-of-area teachers to up-skill, as with the successful maths programme. This would allow biology teachers to do a course in physics or chemistry to relieve the shortage.
Fifthly, make teaching more attractive and more effective by an in-career CPD programme for all teachers on a rolling basis e.g. one term off in five years. If properly organised and implemented this would also provide opportunities for new teachers to gain experience and fulfil their registration requirements. This would also include opportunities for teachers to be involved in action research.
Sixthly, to promote take-up of LC sciences, ensure that JC science students meet and are taught by teachers of the main sciences.
Seventhly, ensure that all schools offer all LC science subjects so that all students have a chance to take them.

At the moment there is no planning, except perhaps at primary level, of teacher provision in relation to teacher requirements in schools and none at all in relation to specific subjects. If there is a real shortage in specific areas then there needs to be specific, targeted action. Stupidity has been defined as continuing to do the same thing and expecting different results. The issue of teacher shortages illustrates such thinking.

Teachers in schools
The number of registered teachers (2016/2017):

Subject	Males	Females	Total
Ag. Science	239	547	786
Biology	886	2,845	3,731
Chemistry	726	1,547	2,313
Physics	620	595	1,215
Phys+Chem	16	6	22

Except for Physics, female teachers exceed male teachers. In 2017 41 Physics teachers registered with the Teaching Council.

Limitations: most teachers are registered to teach more than one subject; also some registered teachers are no longer teaching their subjects, for various reasons e.g. career breaks, moved into administration etc.

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Schools offering science in 2017/18 (Source: SEC)

Total number of second-level schools: 714

Leaving Certificate Subject	No. of schools offering	% of total schools
Agricultural Science	429	60.1
Biology	691	96.8
Chemistry	602	84.3
Physics	558	78.15
Physics with Chemistry	79	11.1

Comments: The good news in these figures is that the number and percentage of schools offering Chemistry and Physics has gone up. More schools offer Chemistry than Physics and if we assume that most schools offering Physics with Chemistry don't also offer Chemistry or Physics separately, then the majority of students can take one or more of the physical sciences. The lack of popularity of these subjects is not due to their availability, assuming students have a free choice. The article later in this issue (p.43) looks at what makes a successful Chemistry school, what can schools do to make the physical sciences more attractive to students.

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Conferences 2018

ISTA Conference 2019

23-25 March
Athlone IT

Congratulations to Brendan Duane, pictured with past recipients, on the award of the BioPharmaChemical Ireland Science Educator of the Year 2018. He is shown here with some past recipients of the award.
The awards were originally set up by Dr. Oliver Ryan in 1984 and presented by Siobhan Dean from BPCI.
http://www.ista.ie/bpci-science-educator-of-the-year-2018/

Next year the conference will be in **DCU, St Patrick's Campus, Drumcondra & All Hallows College** on **12th - 14th April** and it is the responsibility of the Dublin Branch.

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12th Chemistry Demonstration Workshop

There will be another Chemistry Demonstration Workshop, from 4-5 July, at the University of Limerick. This is a residential course with a booking fee of €110. It will run for 3 full days from Wednesday morning to Friday teatime, a little shorter than previous years. It will only run if we have enough participants.
For more details or to book a place, please email Aimee Stapleton or Martin McHugh at SSPCOutreach@ul.ie before the end of May.

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7th BASF Summer School for Chemistry Teachers

Tuesday 26th June and Weds 27th June in the Eureka Centre University College Cork.
Contact: d.kennedy@ucc.ie

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SMEC 2018

Connecting Research, Policy and Practice in STEM Education
26 June
St. Patrick's College, DCU
The Centre for the Advancement of STEM Teaching and Learning, CASTeL, invites you to the 8th Science and Mathematics Education Conference (SMEC) at DCU Institute of Education, St. Patrick's Campus, Tuesday 26thJune 2018. The recent STEM education policy statement 2017 - 2026 (Government of Ireland, 2017) recommends the enhancing and embedding of existing good practice in STEM Education and calls for attention to establishing what is necessary to provide a quality STEM education experience. In this context the theme for this year's conference is *Connecting Research, Policy and Practice in STEM Education.*
https://www.dcu.ie/smec/smec-2018.shtml

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International Chemical Education Conferences

The even years are full of chemical education conferences. There are three major conferences this summer, so there's plenty to choose from. This summer sees the following conferences:

25th International Conference on Chemical Education, ICCE
10-14th July, University of Sydney, Australia
www.icce2018.org/

25th Biennial Conference on Chemical Education
July 29 – August 2, University of Notre Dame in South Bend, IN, USA
www.bcce2018.org

14th European Conference on Research in Chemical Education, ECRICE
This will be held in Warsaw, Poland from 2-6 September. The theme is: **"Educational innovations and teachers' needs"**
www.ecrice2018.pl/

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37th ChemEd Meeting

"Bridging the Gaps".
20th October
Trinity College. Dublin

The planning for this year's ChemEd-Ireland conference is well underway with the one-day meeting being hosted by Trinity College Dublin for the first time. The School of Chemistry at TCD is currently arranging the meeting for Saturday the 20th of October in Dublin city centre, under the theme of "Bridging the Gaps". The committee for this year's conference is led by Dr. John O'Donoghue, who is the Chemistry Education Coordinator for the Royal Society of Chemistry and Project Coordinator for Spectroscopy in a Suitcase. This year's conference aims to help teachers inspire students to go into Leaving Certificate chemistry from Junior Cycle Science and Transition Year, as well as to encourage students to pursue chemistry careers after school.

The day will be officially opened by Prof. Mike Lyons, head of the School of Chemistry at Trinity College Dublin. The school was recently ranked in the top 100 worldwide by the QS world rankings, a fantastic achievement for an Irish university. The morning session will start with Dr. Michael Seery, now based at the University of Edinburgh, who will speak to us about ideas for practical assessment from his experiences of teaching 1st year college chemistry students. Prof. Sylvia Draper will then give us an overview of the extra-curricular programmes available for students such as the annual Chemistry Summer School, Nano in my Life by CRANN and TY Programmes. Another unconfirmed speaker will take the floor just before lunchtime with a talk based around education and ideas. Workshops will take place either side of lunch and confirmed so far is one run by Junior Cycle for Teachers (JCT), and another based on Lab Safety, Labelling and Storage.

The afternoon will kick off with our Academic Keynote speaker, Prof. Valeria Nicolosi from the AMBER research centre and previous recipient of the SFI Early Career Researcher Award. She has received multiple ERC (European Research Council) grants to the tune of €12 million and her work focuses on advanced 2D nanomaterials, particularly in relation to energy storage and efficiency. The afternoon will continue with short snappy talks from industry professionals about their day to day work, to give us an idea of modern industrial chemistry careers. Finally, the day will finish with a talk by Dr Fiona Desmond from the State Examinations Commission about the recent practical assessment trials, the Leaving Cert Chemistry exam paper and changes to the Leaving Cert science subjects.

This year's team is hoping to see many of you in attendance at the first ChemEd-Ireland hosted by Trinity College Dublin and we hope the accessibility of LUAS, DART, Bus and car will make the journey easy for you. Bookings: https://www.eventbrite.com/e/chemed-ireland-2018-tickets-45677934933
John O'Donoghue
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RSC Ireland Updates (Spectroscopy in a Suitcase Programme Update)

John O'Donoghue
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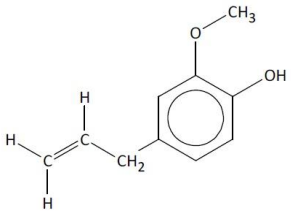
Spectroscopy features on the Leaving Certificate Chemistry curriculum and usually appears as an optional question in Section B of the exam paper. However, it has been the least answered question across the entire paper over the past decade. An example of such a question is given below.

(*h*) The structure of eugenol is shown.

(*i*) Write the molecular formula of eugenol.

(*ii*) Name a spectroscopic technique that could help confirm the identity of a sample of eugenol.



Spectroscopy in a Suitcase (or SIAS for short) started in the UK in 2007 as a partnership between three universities and the Royal Society of Chemistry (RSC). It arrived in Ireland in 2014, but workshops didn't start until early 2015 in

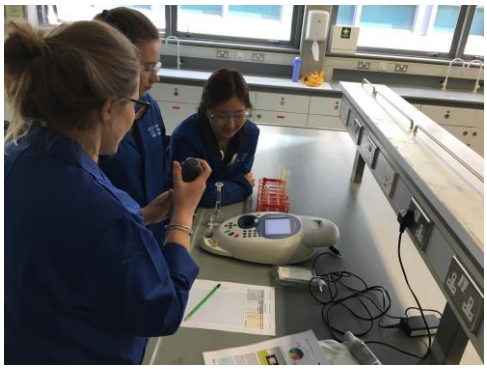
Cork and Dublin. The RSC Education Coordinator based at Trinity College Dublin, Dr. John O'Donoghue, also acts as the Project Coordinator for SIAS in the Republic of Ireland. In conjunction with RSC colleagues based in Cambridge, John coordinates SIAS on the ground in Ireland, through the various hosts (Institutes of Technology or Universities) who bring infra-red (IR) and ultraviolet (UV) spectrometers out to local schools with undergrad/postgrad chemistry students.

The workshops are usually 80-90 minutes in length and are based around a scenario such as a murder mystery, with students getting the opportunity to run various samples on the instruments. The programme began with Trinity College Dublin, University College Cork and Cork Institute of Technology as the first hosts. Through three successful Science Foundation Ireland (SFI) funding applications written by John and his RSC colleagues, it has since expanded to now include University College Dublin, the University of Limerick and most recently the Institute of Technology Sligo.

With IT Sligo now joining the team for the 2018/2019 academic year, counties such as Mayo, Sligo, Donegal, Roscommon and Leitrim will regularly now receive free SIAS workshops. In addition to expanding the number of host institutions, funding has also been increased for the current hosts, which gives them further flexibility for travel and staff costs. The increase in funding allows the hosts to bring the SIAS kits into rural areas on a regular basis. Last year Longford, Cavan, Monaghan and Carlow received workshops for the first time due to the increase in funding provided by SFI.

Over the past 3 years the Irish SIAS hosts have completed 500 workshops with 8,000 students in 250 schools across all 26 counties. (See map above showing schools visited.)

The generous support by SFI has also allowed the RSC Ireland team to expand and trial other activities by using the SIAS kits for teacher workshops, outreach events such as the BT Young Scientist and various Transition Year Programmes. In October 2017 Dr. John O'Donoghue provided the first ISTA branch SIAS workshop in the Tralee Education Centre with 12 attendees. There are now provisional plans to expand this concept to the Dublin Branch of the ISTA and others in 2018. These teacher workshops will be run in two parts over an evening, with a presentation about the RSC resources for the first 45 minutes, followed by a break and then a SIAS workshop for a further 45 minutes. The focus is on the assessment of practical skills for Leaving Certificate Chemistry students, while also giving teachers the opportunity to ask questions and run samples on the instruments.



The RSC Ireland team will be bringing the SIAS kits around to teachers over the summer, in particular to the UCC BASF Chemistry Summer School run by Declan Kennedy (26 and 27 June). They will also be visiting Waterford IT for the annual Science Summer Camp in June and will again be running demos at the annual Ploughing Championships in September. For Science Week in November each of the host institutions are usually very busy with the SIAS kits but there are already some plans for joint events again for 2018.

You can follow John on twitter for updates on events and activities in the Republic of Ireland @johndhodonoghue and now the RSC Ireland team also as a twitter handle as @RSC_Ireland_Edu, which covers all RSC activities on both sides of the border.

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Winners of SSPC/iCrag National Crystal Growing Competition

Aimee Stapleton, Martin McHugh, Sarah Hayes and Laurie Ryan
SSPCOutreach@ul.ie

Winners of the National Crystal Growing Competition, jointly organised by the Synthesis and Solid State Pharmaceutical Centre (SSPC) and the Irish Centre for Research in Applied Geosciences (iCrag) were announced at a special events held in March. The national competition, run in partnership with the International Union of Crystallography (IUCr), is now in its fourth year. The competition enables students to grow their own crystals and increase their awareness and understanding of the importance of crystals in the world around them.

Crystals are all around us, and in every aspect of our lives, from chocolate to medicine to paints and plastics. Most of the medicines we take are made of compacted powders and the individual particles of the powders are in fact tiny crystals. The aim of the competition is for an individual student to grow a single crystal. By participating in the competition, students not only develop practical science skills but also gain insights into the nature of science.

The competition is open to both post-primary school students in Ireland. The competition challenged students to grow a single crystal from a variety of compounds such as salt (sodium chloride), alum, sugar, or copper sulphate. An expert panel of scientists working in the SSPC and iCrag centres judged the competition entries.

The competition winners were celebrated at two special events hosted in the University of Limerick (SSPC) and University College Dublin (iCrag). At the University of Limerick event, the crystal-growing winners were, David Masterson, 1st place, from Melview National School, Co. Longford; Alex Toribio, 2nd place, from Cabinteely Community School, Co. Dublin and Thomas Mason, 3rd place, also from Cabinteely Community School in Dublin. Speaking at the event, Dr Martin McHugh, SSPC Education and Outreach Officer, added: "2017 was a record year for entrants. The crystal growing competition really sparks student interest and teaches them how to be a real scientist. Congratulations to all the deserving winners."

SSPC Co-Director Prof. Gavin Walker with SSPC National Crystal Growing Competition winners, Alex Toribio, 2nd place from Cabinteely Community School, Co. Dublin, David Masterson, 1st place from Melview National School, Co. Longford and Thomas Mason, also from Cabinteely Community School, Co. Dublin with Dr Martin McHugh, SSPC Public Engagement and Projects Officer. Oisin McHugh, True Media.

At the University College Dublin, the winners were Eve Devey, 1st place; Megha Theresa James, 2nd place; Emma Kinane, joint-3rd place (all from St. Paul's Secondary School, Greenhills D12) and Edel Leakey joint 3rd place winner from Virginia College, Cavan. At the UCD event, Dr Fergus Mc Auliffe, Education, Public Engagement and Communications Manager, iCRAG said: "This year's crystal entries again raised the bar for what can be achieved in school laboratories around the country. We are delighted to acknowledge the hard work of both students and their teachers today in UCD and to give the students insight into the many uses of crystals in the earth sciences."

Winners of the iCRAG-SSPC crystal growing competition pictured at UCD: Eve Devey (1st), Megha Theresa James (2nd), Emma Kinane (joint-3rd) all St Paul's Greenhills and Edel Leakey, Virginia College Co. Cavan (joint-3rd)

Speaking at the awards ceremony, Prof. Gavin Walker, SSPC Co-Director said: *"Crystals are very important in science; they are low-costing and high-value route to new and better medicines. It is fantastic to see students being taught how science exists in the real world".*

The SSPC/iCrag National Crystal Growing Competition is going from strength to strength with a record-breaking number of entrants this year. For those interested in competing in next year's competition, the SSPC website provides a step-by-step guide to crystal growing and safety data sheets (www.sspc.ie/crystal_growing).

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STEM Education Policy Statement: 2017-2026

https://www.education.ie/en/The-Education-System/STEM-Education-Policy/stem-education-policy-statement-2017-2026-.pdf

This is a big and comprehensive document and warrants careful study by all stakeholders. A few items from the report will be highlighted here. It setsd out an overall visision for STEM education.

In line with our ambition to have the best education and training service in Europe by 2026, Ireland will be internationally recognised as providing the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behaviour, confidence, and persistence, along with the excitement of collaborative innovation.

In developing this Policy Statement, three key principles have been identified that will underpin all STEM education initiatives.

Principle	Descriptor
STEM is about igniting learners' curiosity so they participate in solving real world problems and make informed career choices.	• STEM education should encourage learners to be curious about the world they live in • STEM education should be relevant to the issues facing society • Learners should develop skills to enable them to be active citizens, ensure personal well-being, engage with modern communications and media in a critical way and make informed and ethical choices • STEM education should be for learners of all backgrounds, ability and gender • Learners should be enabled to make informed choices about careers in STEM and related areas
STEM is interdisciplinary, enabling learners to build and apply knowledge, deepen their understanding and develop creative and critical thinking skills within authentic contexts.	• STEM education should deepen conceptual understanding of and interest across multi-disciplinary fields, allowing learners to address global and societal issues • Learners should have opportunities to explore concepts and engage in problem-solving, while developing their knowledge and skills
STEM education embodies creativity, art and design.	• There are strong practical and creative components to STEM education that should provide learners with opportunities for real-world and inquiry-based tasks • Learners should have opportunities to design, create and make while exploring and experiencing STEM education

These principles will help guide the Department, schools, leaders, teachers and key stakeholders to play a proactive role in providing a high-quality STEM experience for our young people. (p. 9)

While there are many strengths in STEM education provision in Ireland at present, a number of challenges also exist. These include the need to

• Ensure that Irish students' learning in STEM disciplines significantly improves, including the further development of skills such as problem-solving, inquiry-based learning and team working to address demands from the world of work

• Increase the number of students choosing STEM subjects in post-primary schools, those progressing to STEM pathways in Further or Higher Education and those who take up careers in STEM

• Increase participation of females in STEM education and careers

• Raise interest in, and awareness of the range of exciting careers in STEM

• Ensure young people sustain their involvement in STEM education

(p.10)

In each of these areas of ambition, demonstrable improvements will be made. One of the immediate areas of work will be to identify stretch targets with associated benchmarks and key performance indicators. Progress towards the achievement of our ambitions will be realised through a strategic planning process, developing and monitoring new initiatives and learning from best practice at home and abroad. The areas of policy development and action span four pillars as follows:

Pillar 1. Nurture learner engagement and participation

Pillar 2. Enhance early years practitioner and teacher capacity

Pillar 3. Support STEM education practice

Pillar 4. Use evidence to support STEM education

Success in these areas of policy development and action will result in the following outcomes by 2026

Outcomes for Pillar 1. Nurture learner engagement and participation.
• All early years settings, schools, leaders, parents, teachers and learners will have a high awareness of the importance of STEM education
• Research and monitoring of the uptake of STEM subjects by all learners in post-primary schools in place
• Uptake of Leaving Certificate Chemistry, Physics, Technology and Engineering to increase by 20%
• Uptake of STEM subjects by females to increase by 40%
• Quality career information available to all schools for learners and parents • Increased partnerships between schools, business and industry, public sector bodies, research organisations, further and higher-level institutions, and the wider STEM community.

Outcomes for Pillar 2. Enhance teacher and early years practitioner capacity.
• A quality assured programme of STEM professional development will be provided to all early years practitioners, primary teachers and to all relevant teachers in post-primary schools
• Teachers and early years practitioners will have engaged with professional learning opportunities and will embed STEM into their teaching practice to include the use of digital technologies
• Teachers and early years practitioners will adopt an inquiry-oriented approach to their teaching and learning, and their practice will be informed by their engagement in and with relevant research
• Teachers and early years practitioners will use a cross-disciplinary approach incorporating pedagogical content knowledge and understanding developed in and across the four disciplines
• All programmes of teacher education across the continuum will take account of the STEM Education Policy Statement
• Robust relationships between schools and HEIs, research agencies, business and industry, professional bodies, science centres, media and government agencies are in place.

Outcomes for Pillar 3. Support STEM education practice.
• Teachers and learners will have access to relevant, high-quality and up-to-date curricula across all of the STEM subjects and areas at early years, primary, junior cycle and senior cycle levels
• Early years practitioners and teachers in early years setting and schools will have ready access to examples of highly effective practice in STEM education through – advisory visits from the Department's Inspectorate and support services – online materials and publications – professional networks and online communities of practice
• STEM practice will be supported through individual and collective reflection, through school self-evaluation and focused inspection in schools and early years settings
• Learners have access to co-curricular and out-of-school STEM learning opportunities with a 20% increase in extra-curricular STEM activities in schools in every region
• STEM awards for Primary and Post-Primary schools in place
• Partnerships in place with Arts education promoting creativity, universal design and design thinking skills into all STEM learning experiences
• Partnerships in place with business, industry and the research community.

Outcomes for Pillar 4.
Use evidence to support STEM education.
• STEM education research available to include best practice in STEM teaching, learning and assessment, rates of participation, attainment, attitudes to STEM, graduate numbers and STEM related skills
• Review mechanisms in place for established STEM education programmes and trials
• Quality in STEM education will be reported upon regularly by the Department's Inspectorate.
Achievement will be in three phases
Phase 1: 2017-2019, Enhancing
Phase 2: 2020-2022, Embedding
Phase 3: 2023-2026, Realising
(pp 14-15)

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Pioneers of Science Education

Dr Peter Childs has a new series running in the ISTA's *SCIENCE* magazine on Pioneers of Science Education (PoSE). Each article looks at someone who made major contributions to the development of science education. The first two articles looked at Maria Edgeworth (PoSE #1) and Richard Dawes (PoSE #2), and subsequent articles will feature Mrs Jane Marcet (PoSE #3) and Jams Wilson (PoSE #4). If some or all of these names are new to you, check out the articles in *SCIENCE*.
(http://www.ista.ie/category/science-journals/)

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Proceedings ChemEd-Ireland 2017
University of Limerick
Sat. 21st. October

It has been the normal practice for many years to publish the Proceedings of the ChemEd-Ireland conferences in the Spring issue of *Chemistry in Action!* in the following year. This provides a permanent record of the conference and also widens its impact. This year we have all the main talks available for the Proceedings and the organisers would like to thank the speakers for their time and effort in producing a written version of their talks.

Emeritus Professor John Sodeau (UCC) opened the conference with a lively, informative and challenging talk on climate change. He was followed by Emeritus Professor William Reville (UCC) who talked about scientific literacy but also savaged enquiry-based learning as the method for teaching science. You may well find this article controversial and I would welcome replies. Dr Stephen Ashworth (UEA) brought his outreach lecture on Kitchen Chemistry to Ireland for the first time, and showed us how many familiar demonstrations could be used to engage young people. Two talks on research in UL followed by Professor Mike Zawarotko and Dr. Micheal Scanlon. You can link to ppt presentations at: **https://bit.ly/2FFxnkq**

Some images from ChemEd-Ireland 2017.

Every Breath You Take

Eva Philbin/CHEMED Lecture 2017

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Abstract

This article represents a flavour of the Eva Philbin lectures presented in 2016 and 2017 at University College Cork, Dublin Institute of Technology, Limerick Institute of Technology and for the ChemEd 2017 conference at University of Limerick. However, some spices are added to this essay from a further lecture made at the National Sustainability Summit held in January 2017 called, "Facts, Fables and Fantasies about Climate Change".

Preamble

You can probably work out from the thumbnail sketch that my formative research years in photochemistry and atmospheric chemistry were between the mid-70s and early-80s. It was a period when I first heard the words, climate change, and the first time in my life that I smelt ozone made by a photochemical smog (in Los Angeles).

When I began writing the words that would become the Eva Philbin Lecture of the Insttiute of Chemistry of Ireland, three songs kept coming to mind from those years. One by the Hollies, one by Thunderclap Newman and one by the Police. Yes, pop trivia lovers they were: "The air that I breathe"; "Something in the air" and the one that I finally chose as a title, 'Every breath you take'. With that settled then I decided the talk would be an "edutainment" and not at all like my normal undergraduate or conference lectures. That was an important decision because, as the world made its Rake's Progress down 2016 and 2017, "post-truth" and "fake news" became the Oxford and Collins Dictionaries "words of the year". So I became determined to play my part in telling clearly some "real truths" to the "real world" about the inseparable environmental issues that have been termed Climate Change and Air Pollution/Quality.

For those of you like graphs and pictures then go to the video of the pilot lecture at: https://www.ucc.ie/en/crac/newsevents/2016-eva-philbin-lecture-series.html and, I hope, enjoy. The actual lecture I gave at CHEMED 2017 is to be found on the same site at https://www.ucc.ie/en/media/research/crac/ULCHEMED_EveryBreath-you-take_2017_FINAL.pdf. (In fact there is a lot of useful information and opinions on the crac.ucc.ie website regarding atmospheric chemistry if you would like to visit). Here I write down some more self-controlled thoughts than ever possible in a public lecture. To my mind it is an essay of the type you might read in *the New Yorker* magazine focused on the science and the roles that the media, the public and especially teachers have to play in protecting the air we breathe.

Air and Atmosphere

The Sun, Earth and the other planets in our Solar System were born about 4.5 billion years ago. The dominant body is the Sun holding about 99.9% of the total Solar System mass. It is a nuclear reactor releasing energy equivalent to 100 trillion kg of dynamite exploding every second. Heat, light and solar wind reach all the planets from this continuous, dynamic process but it is only on one, Earth, where human life has developed. Why?

Of all the planets, Earth has the greatest density with its chemical composition being mainly iron and rock. The gravity that results helps hold on to the gases, vapours, droplets and solid particles released from the surface of the planet, in a surrounding envelope we call the atmosphere. (That word is of Greek derivation from *atmos* meaning vapour and *sphaira* meaning sphere). In the beginning, volcanic activity released (outgassed) the initial atmospheric ingredients from Earth's mantle, with the most important one being the lightest element, hydrogen. This gas subsequently fixed the other available simple elements, carbon, nitrogen and oxygen as methane (CH_4), ammonia (NH_3) and water (H_2O) molecules. However, the solar wind could then whisk our atmosphere away if not prevented. Fortunately for us, the flow of liquid iron in the Earth's core gives rise to a magnetic field, which serves to deflect the incoming charged particles from the Sun. Then photochemistry can take over.

In the prebiotic world, high-energy (ultra-violet, UV) sunlight broke the bonds of the simple molecules contained in our initial atmosphere, giving rise to other combinations of atoms, the most important of which was carbon dioxide (CO_2). The Sun also sends out lower energy, infra-red (IR) light, which simply makes molecules hotter by causing them to vibrate. Therefore, once we developed a stabilized atmosphere with ingredients like water, methane and carbon dioxide, heat became trapped and the Earth's surface could warm up, eventually, to the sort of temperatures we experience today. It is just how a greenhouse works but with atmospheric ingredients rather than glass trapping the energy. If we had no atmosphere then our surface temperature would be about -18^{o}C, like the Moon.

Today, Earth is surrounded by a fluid atmosphere comprising a mixture of gases, vapours, droplets and small solid particles. Our worldwide average temperature is about 14-15^{o}C. The chemical composition is dominated by molecular oxygen and nitrogen contributing 21% and 78%, respectively. (The missing 1% and the other components will be discussed in more detail later). The proportion of oxygen allows us to breathe effortlessly and not to be afraid of striking a match. We call this the Goldilocks mixture or more familiarly, Air. There is no Air on any other planet in our Solar System, although they do all have atmospheres. For example, the atmosphere of Venus consists of about 96.5% carbon dioxide and 3.5% nitrogen. That atmosphere is not a mixture we should be aiming at breathing in!

700 million years ago Earth was like a snowball or at least like a slushie frozen drink. Water was trapped on the surface as ice until the carbon dioxide content of the atmosphere increased sufficiently to trap enough heat to turn the ice into liquid. Then complicated combinations of carbon, hydrogen, nitrogen and oxygen atoms could be made, eventually forming cyanobacteria. From their name it is obvious that they are coloured and so can take up visible light from the Sun. And that was a turning point for life as we know it on Earth, because these micron-sized photo-reactors are able to turn carbon dioxide and water into oxygen gas. We term this process photosynthesis and is more familiar today to us in relation to the plant molecule called chlorophyll. Eventually DNA was formed, a biochemical that could act as a building block to help construct a world in which plants and animals existed side by side in a mutually dependent relationship. We still take part in this vital, synergic connection with animals taking up oxygen and releasing carbon dioxide and plants doing the opposite.

Weather and Climate

We all know that the weather is an important, maybe the most important, topic of conversation in Ireland. Even Seamus Heaney wrote in 1979: "my people think money but talk weather". Today he might have written "my people think money but talk climate change". Countless articles about global warming and how the climes they are a changin', have been written over the past few years. So where to begin here? Like many others I have chosen to outline first why we have climate and weather and what is the difference between them.

Planet Earth orbits around the Sun over a period of one year. It also rotates and wobbles on an axis that is tilted toward the Sun at an angle that maximizes during June's summer solstice. At that time a maximum amount of sunlight reaches the Northern hemisphere and leads to the longest day. At the winter solstice, in December, the tilt away from the Sun is maximized leading to the longest nights. We divide the full year between toward, away and back to toward the Sun into four seasons, with each day containing a differing amount of time between sunrise and sunset. The overall effect is for the Sun to score a concentrated direct hit on the equatorial region of the planet throughout the year. But at the poles the hit is much more spread out over area and time leading to much colder conditions being experienced there. Heat flows from hot to cold and so the hot air over the Equator flows to the polar cold by means of the fluids we call our atmosphere and oceans.

In the air the energy is transferred by winds produced by the motion of the Sun's rays over the rotating Earth. To understand how winds develop imagine an area the size of Phoenix Park in summertime when the Sun is directly overhead and you feel very warm. After sunset the Sun will have moved on and you will feel cooler. The air experiences the same conditions but hot air rises because it becomes less dense exerting lower pressure (by the Ideal Gas Law, PV = nRT), which will necessarily be replaced underneath by cooler, denser air as the Sun moves on its path. Wind results as the area equalizes the pressure between the low altitude cooler air and the higher altitude warmer air. Obviously, there will also be important but complicated interactions with the

Oceans. For example, the balance between water vapour, liquid and ice is temperature dependent. Shifting the delicate balance between them, by increasing surface temperatures, can lead to extreme weather events, like Hurricane Ophelia. The complex linkage between air and oceans makes accurate weather forecasting and climate predictions so difficult in parts of the world like Ireland.

We have about a half dozen measures to define our weather and climate: wind direction/speed; precipitation, temperature, sunshine, visibility and cloud. The difference between the label, weather, and the one we call climate, is simple. The first reflects the measures in the short term (minutes, hours, days) and the second represents a much longer term average (30 years and more). The most intuitive way of thinking about it that I have ever read is to consider the weather as expressing a mood (like anger or joy) and climate, a personality (like calm or mercurial).

The winds act as an air-conditioning system for our planet moving in all directions at many speeds and so they transfer heat from the equator to the poles. But they also transfer air pollutants over periods that vary from about 1-2 months within a hemisphere and about 2 years between hemispheres. That is at least in the air close to our surface. This time-scale contrasts with pollutants released from processes like combustion and agriculture to reach about 25 km altitude: they take 5-10 years for reasons related to the temperature structure of our atmosphere as discussed below.

Natural and Anthropogenic

Our atmosphere reaches an altitude of about 120 km but climate scientists do not think of it as one continuous covering. Rather they divide it into layers, not arbitrarily, but because of temperature profiles. The region that extends to about 10-12 km in altitude is called the troposphere (from the Greek meaning "changing"). It gets cooler as you move upwards because there is much lower pressure of atmospheric gases like oxygen. Climb a mountain and you will know what I mean. It is also a turbulent, highly mixed air because a balance is struck between the lower pressures at higher altitudes, hot air rising because of our everyday activities and sunlight hitting the surface. This essay focuses on activities in the lower region of the atmosphere but you probably have heard of the interesting chemistry that occurs in the warming layer that sits above the troposphere and we call the stratosphere (from the Greek meaning "layer"). Yes, I mean ozone depletion but that is for another day.

We owe the process of photosynthesis the main debt for producing breathable air containing 21% oxygen and we owe bacteria and volcanoes for the nitrogen content at 78%. Most of the rest is the inert gas, argon, at 0.9%. So, that leaves just 0.1% of trace gases to account for, including carbon dioxide. The sources of these chemicals are either from natural processes or anthropogenic/human activities. Many people are amazed that the most important aspects of atmospheric chemistry are related to these trace substances that may be present at levels as low as parts (trace molecules) per trillion (air molecules), labelled universally as ppt.

Natural sources include lightning strikes to crack nitrogen in the air to produce nitrogen oxides or volcanoes to release sulfur gases and solids or even desert storms to transport sand and dust over many thousands of kilometres. Nature does not just release chemicals into the atmosphere and much research is now being done to monitor the release of biological materials like pollen, fungal spores and bacteria as it happens, in real-time, because the information is of real use to at-risk members of the public like asthmatics. We create air pollution with transport (car, ships, aeroplanes etc) being important, as well as domestic solid fuel (DSF) burning (coal, wood peat etc) and also agriculture (cattle eructations, fertilizers, poor husbandry of livestock etc).

The resulting air pollution has two main effects on life on Earth: (i) Health and Wellbeing; (ii) Climate Change. It is easy to write a few names of the major pollutants down, but their effects can be many and varied. Anyway, here is my list: ammonia, nitrogen oxides (often termed NO_x as the sum of nitric oxide and nitrogen dioxide), nitrous oxide (laughing gas), acid rain/sulfur compounds, carbon-containing particulate matter, hydrocarbon vapours and finally ozone and carbon dioxide. There is often debate about whether to call the final two chemicals, pollutants, because they are essential to life…..at the right levels. But I am including them and will discuss their less benign effects below.

The one ingredient of air that is most definitely not a pollutant is water, the essential of life. Its continual cycling thoughout the planet into plants, rivers, the air, the poles, oceans, whiskey and

humans is entirely dependent upon temperature. Its environmental behaviour may prove to be an insuperable problem for us to solve if, eventually, the average surface of planet Earth moves to 20ºC or more.

Do we wish to face desertification, extreme weather events, flooding, polar ice cap and Greenland melting? Do we wish to increase cancer rates, cardiovascular problems, dementia and asthma? I think not, but we are moving along that pathway mainly because of our demand for carbon-based energy and the combustion process used since stone-age times. It is time to move on, world, and to include a blend of nuclear, wind and solar.

Climate Change and Air Pollution

Although the terms are often separated, Climate Change and Air Pollution are inseparable. They go together like bacon and eggs or pie and mash, if you happen to come from the East End of London. The most obvious chemical connection between them is carbon-containing particles that are released in a variety of combustion processes. We often term these materials soot or black smoke or, more recently, particulate matter (PM) but no matter the name or even the exact composition, which can range from elemental carbon to small solids containing thousands of organic compounds, they affect both our health by breathing in and also our climate by absorbing heat radiation.

The intimate connection between the two terms has been unappreciated by politicians and policymakers in the past. It still is as the recent Citizens Assembly on climate change showed. That is why, in Ireland at least, diesel fuel and car taxes are so much cheaper than petrol equivalents. Although part of the decision may be due to the powerful trucking and agricultural lobby in Ireland, a lot is due to the scientific ignorance of most government Ministers about atmospheric chemistry. Hence diesel is probably somewhat better kilometer for kilometer than petrol in releasing carbon dioxide but it is far worse for emitting toxic nitrogen dioxide (and often carbon particles too).

Climate change and health are set up to do battle in this scenario and the public's day-to-day well-being suffers as a result. Hence it is much more appropriate to consider Air Pollution and Climate Change as two sides of the same coin with the coin being made of carbon. In this model we can separate them but not divide them and then it becomes obvious that there is no conflict between them.

Having said that I am actually going to separate the two topics because it is easier to explain them that way.

Climate Change

It has always struck me as amusing that somebody called Cole Porter wrote a song called "It's too darn hot". And although the burning of fossil fuels will take a central role in my discussion of the global warming we are experiencing today, I am going to start 700,000,000 years ago when our planet was frozen and compare it to our blue planet of today, if only to say that Earth has experienced climate change in a purely natural way. As discussed above, the atmosphere developed over that time-span crucially included carbon dioxide and water vapour that, because of their molecular structures, could let high energy UV light through to the surface where photosynthesis was promoted (and therefore life). Some of the sunlight's energy is used up in that process and what is left is the much less energetic wavelengths we call IR, which cannot escape the planet as natural re-radiation because the water and carbon dioxide are not transparent to heat; rather they absorb it. The overall process is now often called the **Natural Greenhouse Effect.** Over the very long time-span between pre-historic times and pre-industrial revolution times (~1750-1830), the Earth reached a state that was not too hot and not too cold to sustain a temperate existence for us and other life on Earth.

After 1830 though, when carbon combustion became central to our energy, industrial and economic demands, the amount of carbon dioxide released increased dramatically from a value of 280 parts per million (ppm) then to over 400 ppm today. One Nobel Prize winning chemist (Svante Arrhenius) predicted in 1896 that a mean increase for temperature on the planet of 5-6 C would occur if we doubled the carbon dioxide level to ~560 ppm. So we have known for some time what might happen if fossil fuels were burnt unchecked.

Climate change is happening; it is inevitable with the pathway we are on. Countless graphs, models and diagrams show the inexorable increase of global temperatures over the last 150 years with the most dramatic increases being measured in the last 10 years. As I write this article NOAA (National Oceanic and Atmospheric Administration) is once again reporting that the

2016 remains the hottest on record and 2017 will be in the top three hottest [1, 2] At the same time the Observatory on Mauna Loa, Hawaii showed that the annual increase of carbon dioxide measured there was 4.5 ppm. The figure is worrying because over the last 60 years of measurement the average annual rates of increase were about 1-2 ppm. In 2016, we reached a peak of ~407 ppm at Mauna Loa in May and ~410 ppm in 2017. And at no point, in either year, was the amount measured to be lower than 400 ppm. [3]

So what is happening now and what might happen in the future? We can term what is going on currently as an **Enhanced Greenhouse Effect**. The best way I have of describing it is to make the comparison of Earth's atmosphere acting as a thin woolen shawl with holes in it up to 1750-1830. After that time by adding more carbon dioxide (increasing the thickness of the wool) and by filling in some of the holes (other pollutant Greenhouse Gases, GHG, like methane, nitrous oxide and chlorofluorocarbons) we are beginning to overheat. In fact the "other" contributions add about 40 ppm currently to our carbon dioxide equivalent loading *i.e* in 2017 we actually reached about 450 ppm equivalent in May.

The final results of our behaviour, in the not too distant future, might be catastrophic, leading to millions of climate refugees. In the meantime we are seeing cold seas like the Bering Sea warming and in so doing disrupting the plankton/fish food chain causing the puffin population to be killed off. Sea-ice volume at the Arctic is now just 20-25% what it was in 1979. Droughts in Darfur and Syria have led to food insecurity, famine and war.

And what do our leaders and politicians and media do? Look at the Dail record for May 2016 to experience the quality of the contributions from one Irish politician on the subject of climate change. Then remember the Australian Senator who blamed climate change on a United Nations conspiracy in collaboration with the World's Banks. And who can forget the President (at the time of writing this article) of the USA blaming the Chinese for the problem. We deserve better.

But I am to blame about climate ignorance too! We scientists have to put the case much more clearly and without jargon, whenever possible. Furthermore the media must show objectivity every time an indefensible fantasy is expressed by a politician, no matter how amusing. That means journalists must have more understanding of basic physical science themselves. Ignorance is not an excuse for them. And the public must learn to listen and discriminate between the truth and lies, no matter where they got their information from.

Greenhouse gases are not the only problem, particles like black (and brown) carbon are too. Volcanic eruptions also spew many particles into the atmosphere sometimes with great vigour. Confusingly, they can actually have a cooling effect on the planet because sulfur particles can reflect sunlight out from the Earth. When that has happened in the past, say in 740 and 1814, harsh winters and crop failures have followed. It will be interesting to see what violent volcanoes do to moderate our enhanced heating budget now we are well into the industrial age throughout the world.

Where there's life there's hope and the Paris agreement signed in late 2015 and now in force gives us some hope for keeping the planet temperature increase well below Arrhenius' prediction to 2^{o}C or so. But most modellers I have spoken to are not hopeful that this can happen in the time available to us and most believe the 3-4^{o}C increase above the pre-industrial time scenario by 2100, maybe earlier, is more realistic. Keep an eye out for the Mauna Loa data on carbon dioxide levels on the internet over the next year because that may be our earliest warning that we are already too late to do anything to keep the planet as we currently enjoy. Keep an eye out for data on whether global carbon emissions are rising or falling, especially in Ireland. And finally, keep an eye out for what President Trump might tweet next on the topic!

Anyway, who cares as long as we've got our health?

Air pollution

Air pollution has been noted since Roman times but the first recorded ban on coal burning was in 1273, when Edward I of England acted to curb urban smoke. Although "smoke" is still a term we employ to describe the quality of our air, we now know a lot more about the ingredients that accompany the combustion process, be they from coal, wood, peat, diesel, kerosene, propane bottles or natural gas.

There are a number of common emissions that can do harm to us in a variety of ways. The main ones are nitrogen oxides (including nitric acid), sulfur oxide chemicals (including sulfates and sulfuric acid), ozone and oxygenated radicals like hydroxyl, metals and metal ions, carbon-

containing particles and often-related organic compound vapours (like formaldehyde and aromatics). Actually, I could list thousands if I needed to name them and had the time, energy and will.

Regarding our health and well-being, the main air pollutants that I have selected to briefly discuss here in terms of air quality (or the air that we breathe in other words) are: Particulate Matter (PM) of various sizes/compositions and nitrogen dioxide.

Particulate Matter

The combustion process of solids produces much PM. They are of a wide range of sizes and we define the main ones as ultrafines (about 500 of them could sit side by side in the width of a human hair), fine that is $PM_{2.5}$ (30-40 in a hair width) and finally, coarse, PM_{10} (5-10 in a hair width). Clearly, these are all of a size to enter into us through our nose or mouth but with differing effects, depending on the size and composition. The largest get into our upper respiratory tract and lead to associated problems particularly for at-risk groups like asthmatics. PM can be particularly dangerous to us because not only can it get into our respiratory systems, while carrying carcinogenic chemicals, but also enter our arteries causing oxidative damage that leads to the build-up of plaque and then stroke or heart failure. (In fact 80% of deaths related to air pollution are due to these causes). The smallest PM can even circulate in our blood stream, reach our brains and are thought to cause dementia.

The mechanism by which the damage occurs to blood flow is that the smaller particles can cause inflammation on arterial cell walls, likely by the production of free radicals from the oxidation of cellular hydrogen peroxide. Plaque builds up as a result leading to arterial blockages and stroke/heart failure can follow. Very recently, a similar type of mechanism has been proposed to explain why the presence of air-borne ultrafine particles can cause an increase in dementia for those living 100 m or less from busy roads. It has been suggested that tyre and brake pad wear give rise to nanoparticles, consisting of the iron oxide, magnetite. This material contains Fe (II), which acts in a Fenton's reagent way on cellular hydrogen peroxide in the brain leading to free radical production, plaque build-up and brain cell degeneration.

Deaths are easier to count than the incidence of diseases like asthma, COPD and cancer on a national scale in many countries. So our attempts at relating air pollution events and air quality levels to mortality is in a much greater state of reliability than other medical associations. This type of work was kicked off in the USA during the 1980s with a campaign called the Harvard Six Cities study.[4] It was shown conclusively, after much searching for confounders and high-level peer-review, that there is indeed an association between $PM_{2.5}$ long-term exposure and death. Depending on the level of particles in the local air, some 5-10 years was shown to be taken off one's life-span. These type of data are now used to show the weeks/months reduction in lifetime depending upon pollutant exposure in particular regions. The total months reduced are added up to give some estimate of life expectancy and increase in mortality at a particular place. By these statistical methods it has been estimated that air pollution led to 2.6 M premature deaths globally in 2012 with about 520,000 occurring in Western Europe during 2014. In Ireland the estimate is 1100-1300 per year from fine particulate exposure with possibly about 200 added to the number when ozone and nitrogen dioxide exposure are taken into account. [5, 6]

The main culprits for producing particulate matter are well-known: (i) exhaust and non-exhaust emissions from cars, trucks and buses; (ii) coal, wood and peat burning in open fires. For more specifics on the chemistry and sources of these pollutants in Ireland then go to the crac.ucc.ie webpage and look at the SAPPHIRE project sponsored by the EPA. I am only going to pass on one surprising fact to you. Burning smoky coal produces 4.3 kg/1000kg burnt of primary $PM_{2.5}$. Peat produces 4.5 kg and wood 9.0 kg. In other words, from a policy point of view in Ireland, there are no health gains to be had if a blanket smoky coal ban is introduced and people simply move over to wood and peat burning in their homes.

Smoky coal is not a good guy by any means in terms of its primary particulate emissions but, because of its sulfur content, its secondary particulate emissions are not good either. Burning smoky coal leads to sulfuric acid production, that turns into particles when it encounters the increasing amount of ammonia that is being released to our air by agricultural activities. Indeed this formation process to make ammonium sulfate particles is thought to be one of the world's biggest killers by air pollution. Farmers beware.

Nitrogen dioxide
Nitrogen dioxide is also a killer because its chemical structure also promotes the formation of highly reactive free radicals in our blood circulation system. And the "extra" release of nitrogen dioxide was the action that VW should not be forgiven for (along with some other car manufacturers). The story needs no repeating here but they gamed ("fiddled") their electronic emission systems results to indicate artificially low levels of the gas from their diesel cars. A criminal act?

Past and Future

Air Quality has not been a high priority to monitor in Ireland over the last ten years. The number of real-time monitoring stations operating reliably throughout the country can be counted on the fingers of one hand. The comparison between that effort and Northern Ireland, UK, or even Tasmania, is embarrassing. Up to date information about air quality in many localities throughout Europe is passed on to the public by means of phone apps and web sites. (See http://aqicn.org/map/europe as an example). Check out Ireland's contribution to the data.

The problem is not just the EPA's; local authorities must play a part too at a much greater level of activity and enthusiasm than is currently shown in most places (Wexford is an honourable exception). But what is fundamentally required here is legislation like most other countries have around the World, that is not simply aimed at living within EU directed limits. First and foremost in the minds of those drafting the new law should be the health and well-being of the population. And for that Ireland needs to scrap its Air Pollution Act with all its negative connotations and introduce the positive message (and teeth) associated with a Clean Air Act. Then local authorities will do something and prioritize their human and financial resources for all of us in terms of air quality.

Things can only get better and the EPA has recently announced a new Ambient Air Quality Monitoring Programme (AAMP) for 2017. [7] This involves the siting of many more real-time monitoring stations throughout urban and rural Ireland. It will roll out over the next 5 years and requires the participation of third-level Institutions (like UCC, which will get its own facility) and, of course, the local authorities. The EPA should be applauded for its initiative, which is based on the ideas presented in a YouTube video by CRAC/Asthma Society that was made in November 2015.
(https://www.youtube.com/watch?v=fzVfUgNJTVw)
Actually we (especially science teachers) can all do our bit: buy an electric car; make sure local authorities install more electric chargers; use natural gas if you are on the grid; do careful husbandry, soil maintenance and use less nitrogenous fertilizer if you are a farmer; if you must burn wood use a very high temperature enclosed stove; tap into the enthusiasm of young people to inform the older generation. I could fill a page with a wish-list but instead I will finish this article the way the lecture ends with a quote by Edmund Burke:
Nobody made a greater mistake than he who did nothing because he could do only a little.

Postscript

As far as I am aware, there are no "alternative truths" in the above essay. I made a conscious decision to include few traditional references because it is not an academic paper, more an informed opinion piece. The article is designed to be thought-provoking and I hope readers will go away and check the facts for themselves. Fact checking is a habit that we all must begin to do much more of in order to bring "post-truthers" to task.

As I said at the beginning: please read the essay alongside the graphics and videos presented in my on-line Eva Philbin lecture.
(http://www.ucc.ie/en/crac/newsevents/fullstory-717902-en.html). A picture tells a thousand words but we should not lose the ability to read 1000 words or more, uninterrupted, on a subject with the consequences that climate change and air pollution have for us all.

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John Sodeau was Professor of Physical Chemistry at UCC between 1998 and 2016; he became Emeritus Professor there in September 2016. Before then he worked as a postdoctoral Fellow and Lecturer at University California Irvine (UCI), later progressing to a Readership at the University of East Anglia (UEA) in UK.

His research interests have been in the area of Photochemistry since his PhD work in the spectroscopic identification of transient intermediates generated by light and trapped at low temperatures. Those studies naturally progressed to research in Atmospheric Science because many of the chemical processes involved are also driven by sunlight. Most of his research now is in real-time sensing of bioaerosols for application in pollen counting, hospital monitoring and green-waste site management.

Climate Change Resources

https://www.skepticalscience.com/One-of-the-best-climate-change-ads-Ive-seen.html

NASA: Climate Change and Global Warming
https://climate.nasa.gov/

Climate Justice | Trócaire
https://www.trocaire.org/getinvolved/climate-justice

Climate Ireland
https://www.climateireland.ie/

Limiting and Adapting to Climate Change: EPA
http://www.epa.ie/researchandeducation/education/educ/limitingadaptingtoclimatechange/

Climate | World Resources Institute
www.wri.org

Climate education resources | National Oceanic and Atmospheric Administration.
www.noaa.gov/resource-collections/climate-education-resources

Climate Change - SERC - Carleton - Carleton College
https://serc.carleton.edu/NAGTWorkshops/climatechange/index.html

Climate Change Teaching Resources - Metlink
…http://www.metlink.org/climate/climate-change-teaching-resources/

How to teach ... climate change | Teacher Network | The Guardian
https://www.theguardian.com/teacher-network/teacher-blog/2014/mar/03/how-to-teach-climate-change

Effects in Ireland - Geological Survey Ireland
https://www.gsi.ie/en-ie/geoscience-topics/climate-change/Pages/Effect-in-Ireland.aspx

This is a small sample of teaching resources about climate change.

The Effective Teaching and Embedding Of Science in Society

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As I start to write this article we are in the middle of Science Week 2017 (12th – 19th November) and you have to be impressed by the number of science events organised countrywide and the generous media coverage Science Week is attracting. Things have changed a lot since I began writing my science column in The Irish Times in January 1995. Of course, this impressive growth in public awareness of science has not been accompanied by an equal growth in the public understanding of science (PUS) and surveys indicate that PUS remains unacceptably low. It is interesting to ponder why this is so because, in my opinion, we should legitimately expect our adult population to be reasonably literate in science given that everybody learns science and mathematics throughout primary and secondary school. I believe that low PUS is explained, at least partly, by ineffective modern teaching methods. And these ineffective teaching methods are only part of a worrying menu of debilitating changes, including a poor maths syllabus at second level and grade inflation at third level, now being stitched into our national educational infrastructure, largely in the interests of social engineering and servicing economic growth.

The public awareness and understanding of science

Science Foundation Ireland (SFI) recently commissioned Amarach Research to survey the Irish public and the science community about some big questions in science today (1). The results show that public attitudes towards science are positive with 64% of the public and 89% of scientists agreeing with the statement "science has a positive impact on people's lives in Ireland" and 60% of the public saying they are interested in science news.

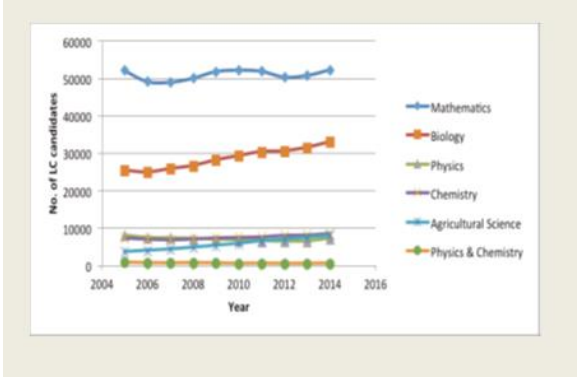
However the PUS situation is far less encouraging. The SFI survey discovered a disturbing misalignment between public and scientific positions on several important issues. For example, 32% of the public, compared to 8% of scientists, cannot agree that climate change is mostly caused by human activities, and 36% of the public, compared to 5% of scientists, do not agree that "vaccines are an acceptable preventive medical treatment". And 45% of the public, compared with 8% percent of scientists, cannot believe that life on Earth evolved through natural selection. Also, very disappointingly, 69% of the public could not name any Irish scientist, past or present, and 72% couldn't name any Irish scientific achievement eg. Dungarvan-born Ernest Walton (1903 – 1995) our only Irish Nobel Laureate in science (Nobel Prize in physics jointly awarded to Walton and John Cockcroft in 1951 for first splitting the atom).

Irish physicist Ernest Walton (1903 – 1995)

The misalignment between mainline science and a significant fraction of the general public on issues such as climate change is doubly disturbing because we now know that simply redoubling efforts to explain the scientific facts to those who publicly dissent will probably not change their minds. We know from the work of Yale psychologist Dan Kahan that when people dislike the implications that scientific findings have for their worldview, ideology or other self-interest, many will refuse to accept the science even if they are scientifically literate themselves (2). It is far

from clear how science communicators can best handle this situation but one thing is clear – we must continue to patiently present the objective scientific facts in order to counter the spread of misinformation. Scientists should also strongly emphasise the negative practical consequences of not accepting scientific findings and guidelines in areas such as climate change and vaccinations, e.g. the implications for economics and general human suffering. And scientists should not be afraid to engage emotionally on these issues.

When considering the general level of adult public science literacy we should remember that. all our school children learn mathematics right through primary and secondary school, all study science up to Junior Cert level and a majority take a science subject in their Leaving Cert. We might expect that the adult population that emerges from this education would be more scientifically literate than is actually the case. I believe that at least part of the reason that reality doesn't match our expectations is because the new teaching methods that are replacing traditional teaching methods are ineffective.



Numbers of leaving cert candidates taking science and maths

The flawed underpinnings of our modern education system

To illustrate one aspect of the problem with modern teaching, consider the following recent quotation from Father Peter McVerry, the well-known Jesuit priest who works with the homeless –"The single most important objective of education should be that children leave school feeling good about themselves ". This quotation was tweeted by the Teaching Council of Ireland and enthusiastically retweeted by several people prominent in educational circles.

I accept Fr. McVerry's good intentions in expressing this sentiment but I must strongly disagree with him because he is promoting a secondary objective of education to primary position. The single most important objective of education is surely education itself, that is that students learn new knowledge. Of course, students feeling good about themselves is also an important objective of education, but it is a secondary objective. Promoting a secondary objective of any enterprise to primary position will cause that enterprise to fail.

The philosopher Roger Scruton uses the game of soccer to illustrate the consequences of substituting a secondary objective for the primary objective. The primary objective of soccer is scoring goals. Soccer has several secondary objectives such as exercise, joy, learning teamwork, etc. Now imagine if one of the secondary objectives e.g. exercise were promoted as the primary objective of soccer – what would happen? The game of soccer would surely decline drastically, dying out as a popular game as the competitive element of scoring goals is demoted. No objective, primary or secondary, is now achieved. Any enterprise not pursued in terms of its primary objective will fail.

Egalitarian policies have been implemented widely in educational institutions in the western world since the 1960s. For example, in the UK grammar schools were effectively abolished. Schools are now viewed as instruments of social engineering as much as institutions for the transmission of knowledge and this has diluted the primary objective of education with predictable negative consequences. Curricula, exams, discipline and admission have all been revised with a view to eliminating distinction and unfair advantage. The previous equality of opportunity approach, designed to eliminate unfair advantages some children enjoy over others due to circumstances of birth, was replaced by equality of outcomes, a goal that in practice schools can neither supply nor even tackle coherently.

The new equality of outcomes agenda is undoubtedly well-intentioned but in practice it has produced a levelling down rather than a levelling up. Exams and syllabi have been 'dumbed down' and standards have fallen. Also, relatively greater emphasis is placed on the less academically able students compared to the more gifted students who are now insufficiently challenged and stretched.

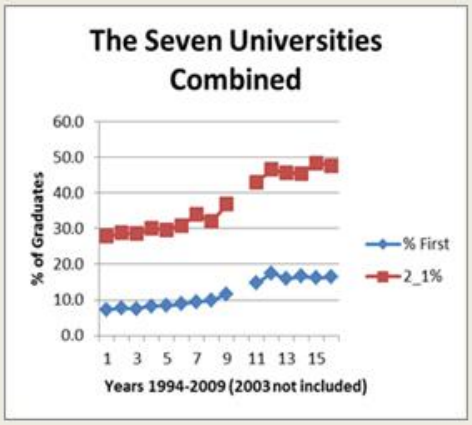
Project Maths

One example of a decline in standards in recent times was the introduction at second level in 2009 of the new maths syllabus called Project Maths. Although I know that some professional mathematicians are in favour of Project Maths, most university lecturers, and all to whom I have spoken, are critical of Project Maths. They would agree with the report (3) prepared by Dr. Cora Stack (Institute of Technology, Tralee) and other professional mathematicians in 2012 that criticised Project Maths as follows. (A) Project Maths is badly flawed both in its syllabus and its methodology. (B) The new syllabus, omitting most of the calculus and also all linear algebra (vectors and matrices), is completely insufficient to support third level engineering and science education and will put our third level graduates at a clear disadvantage internationally. (C) Project Maths will damage the reputation of our universities. (D) Project maths is below the standard employed in other technologically advanced countries.

It is now openly acknowledged in third level institutions that the Project Maths syllabus is inadequate to prepare second level students for third level engineering, physics, mathematics and some economics courses and special 'catch-up' courses in mathematics must now be laid on for incoming first year students to the University.

Grade Inflation at Third Level

A further illustration of the flabbiness that has entered the educational system in recent times is grade inflation in our universities and institutes of technology (4). When I graduated with a B.Sc in the late 1960s a 2.1 honours grade signified that the awardee was an excellent student, but in order to earn a first class honours grade one had to demonstrate quite remarkable ability. In some years no first class degree was awarded because no student in the class demonstrated the outstanding ability necessary to win this grade. This has all changed in recent times as illustrated in the figure for degree grades awarded across the seven Irish universities combined over the period 1994 – 2009. Beginning in 1998 a sharp rise is noted in the percentage of first class and 2.1 grades awarded. Nowadays almost 20% of the graduating class will get a first class honours degree and almost 50% of the class will get a 2.1.



Grade inflation in Irish universities (1994-2004)

Guided learning versus enquiry-based learning

Everybody of a certain age was taught in school by the traditional whole class guided-teaching method where the teacher stands before the class and presents the established body of knowledge relevant to the particular lesson to the pupils. The teacher asks questions of the class to test understanding and then corrects misunderstandings. The teacher illustrates the lesson with examples and where appropriate works through example problems, sets new problems for the pupils to work on by themselves as homework and prescribes readings to encourage students to advance further by themselves. The teacher maintains class discipline, gives extra help to weaker students and doesn't pass on to the next lesson until satisfied that as many students as possible understand the current lesson.

The traditional guided-teaching method includes a certain amount of rote-learning of critically important things such as multiplication tables, mathematical formulae and other rules of thumb, rules of grammar, certain poems, etc. The students also memorise important facts of history, geography, science, literature and so on.

Traditional whole class teaching

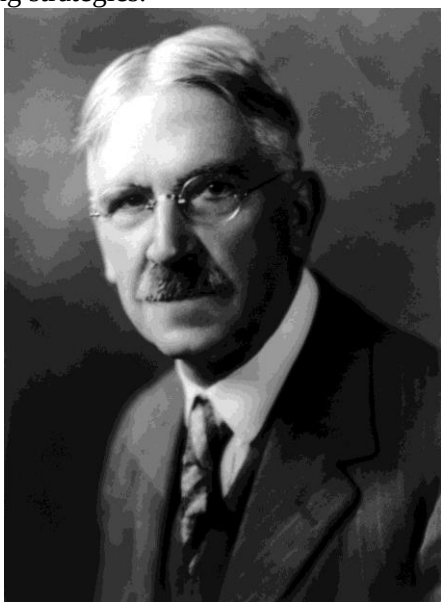
Beginning in the 1960s, influential educationalists began criticising traditional teaching methods as being too rigid, authoritarian and inefficient and started promoting a new form of learning called enquiry-based-learning (EBL). This form of learning is minimally-guided and student-centred with the teacher acting more as a facilitator than as a leader. EBL is a form of active learning that poses problems, questions or scenarios to the student rather than simply presenting established facts and portraying a smooth path to knowledge. EBL is sometimes called problem-based-learning (PBL) or experiential learning – students learn by solving open-ended problems. EBL/PBL is underpinned by the philosophy of constructivism which holds that learners construct knowledge out of their own experience as opposed to passively receiving information.

The new teaching methods largely dispense with rote-learning such as memorising multiplication tables and doing mental arithmetic, give children more control over what happens in class, base learning on childrens' interests , present information in 'preferred learning styles'(whether by sight sound or movement) and constantly praise the students regardless of the quality of work.

These new teaching methods are intuitively appealing but their effectiveness is supported by very little evidence. Indeed the Sutton Educational Trust pointed out in a report (5) in October 2014 that many of these new practices, including using praise lavishly, allowing learners to discover key ideas by themselves , grouping students by ability and presenting information to students in their preferred learning styles, are not only unsupported by evidence but can even be harmful.

John Dewey (1935 - 1998) is often cited as the philosophical founder of constructivism. Dewey and other educational philosophers were very impressed by the natural development of the child, for example how children automatically learn language through immersion in the language. They concluded that learning is natural and that the teacher's proper role is to unobtrusively facilitate this natural unfolding of learning in the child. However, this conclusion seems to be based on a misinterpretation.

Natural selection had sufficient evolutionary time to incorporate an automatic programme for language acquisition into human development. However practices such as writing, mathematics and science arose too recently in human history for natural selection to programme their automatic learning into our natural development. Consequently these skills are very unlikely to emerge in most children through immersion only and are appropriately acquired through explicit learning strategies.



Educational philosopher John Dewey (1859 – 1952)

EBL is supplanting traditional teaching throughout the western world. A recent Report on Science, Technology, Engineering and Mathematics (STEM) Education in November 2016 reccomended to the Minister for Education and Skills that "measures should be put in place to support the implementation of enquiry-based learning as part of the revised curricula for STEM subjects".

Much of the criticism aimed at traditional guided-teaching seems to me to be based on little more than intuition and mistaken correlation and ignores the evidence that supports guided-learning. Many people remember being taught in the traditional manner and not enjoying the experience but they forget that the world then was very different to today. Until relatively recently we lived in a culture in which it was generally accepted that children should be seen but not heard and, of course, this societal attitude penetrated into the classroom also. For example, corporal punishment of children was widely accepted in society and was also used to discipline and punish children in the classroom. Corporal punishment was practiced in Irish schools until1982 when it was legally banned. Many people consequently associate traditional guided-learning with rigidity, authoritarianism and

punishment not realising that this is a false association.

Traditional teaching, authoritarianism, rigidity and corporal punishment paralleled each other historically but there is no natural connection between the traditional teaching/learning method and these other negative factors. Teacher-guided whole class teaching does not entail authoritarianism, rigidity and punishment.

We now know that the traditional teacher-guided method of teaching/learning is actually much superior to the EBL technique. Paul Kirschner and others published a devastating critique of EBL and other minimal-guidance instruction methods in 2006, demonstrating that students cannot learn effectively using these methods because of the architecture of human cognition (6).

Long-term memory (LTM) is the central dominant structure of human cognition. Everything we see, hear and think about is influenced by and dependent on LTM. *The aim of all instruction is to add to LTM. If nothing is added, nothing has been learned.* Working memory (WM) is the cognitive structure in which conscious processing occurs. When processing novel information, WM is very limited in capacity and duration. When processing new information not already stored in LTM, the capacity of WM is limited to about three elements and information stored in WM and not rehearsed is lost within 30 seconds. Kischner points out that *minimal-guidance methods of instruction proceed as though WM doesn't exist, or if it does that it has no limits when dealing with novel information.* Of course it should be noted that when enquiry-learning was first proposed in 1961 the structures and relations that constitute human cognitive architecture had not been mapped.

The implications of human cognitive architecture for enquiry-based learning are immense. Enquiry learning must search the problem space for relevant information. This places a heavy demand on WM and it is not available for accumulating knowledge in LTM. The goal of instruction is rarely simply searching for information. The goal is to give specific guidance to cognitively manipulate information in ways consistent with the learning goal and to store the results in LTM. Guided-teaching specifically supports the cognitive processing necessary for learning whereas much enquiry-based learning is simply spinning your wheels in WM. Human cognitive architecture therefore indicates that minimally guided instruction is very likely to be ineffective. And there is massive evidence, summarised in Kirschner et al's paper (6), that minimally guided instruction is much less effective than guided instruction that supports the cognitive processing necessary for learning. Why is this evidence seemingly ignored by those who so enthusiastically promote EBL? I am not sure but I do know that constructivism has become a liberal ideology for many and ideology is a powerful motivator.

Proponents of the superiority of EBL/PBL over traditional learning methods claim that EBL is better at motivating students and helps to develop 'essential 21st century skills' such as the ability to think critically and creatively and to problem-solve. These critics often contemptuously categorise traditional teaching methods as 'drilling' However enthusiasts for EBL don't seem to realise that in order to think critically about something or to solve a problem you first need to know a lot of facts about the subject or the problem, facts with which enquiry-based learning has not stocked your long term memory. This was cogently explained by Ted Hurley, Professor of Mathematics at NUIG, in The Irish Times, May 11th, 2015 (7).

Conclusions and reflections

Mr. Richard Bruton TD, Minister for Education and Skills, recently said that he has plans to enhance the quality of education in Ireland and predicts Ireland will have the best education system in Europe by 2026. Ireland has a good educational infrastructure across all three levels, dedicated professional teaching staff and a traditional high level of respect for education. The Minister has a solid foundation on which to build, but a shaky superstructure can still be built on a good foundation. Mr. Bruton must design his building carefully. However he voices little or no criticism of the second-rate ideas promoted to him by his advisors - ideas such as enquiry-based learning, Project Maths and the artificially rosy third level grading scheme. In my opinion it simply is not possible to build the best education system in Europe while retaining these three faulty building blocks. If the debilitating changes that have been made to our education system are not reversed it is only a matter of time before we will have to pay the piper.

Guided-learning is undoubtedly the way to go at elementary and intermediate levels of education.

The UK Minister of Education Nick Gibbs recognises this and recently instructed teachers to engage in more whole class teaching, particularly in science and mathematics. I advise Minister Bruton to copy Minister Gibbs's recommendations.

So far I have only said critical things about our education system, but credit where it is due – we are doing many things right. I have spent almost all my working life in the Irish university system, an area that has developed enormously in recent times. Access to third level education has increased hugely over recent decades. When I went to university in the 1960s only 5% of 18 year-olds went on to third level. Today over two thirds of young people go on to third level. Funding for research at third level has also been utterly transformed for the better in recent times. I started doing scientific research in the late 1960s and funding for research was appallingly low throughout most of my working life. However, funding for research at third level has been utterly transformed for the better in recent times and this is now reflected in Ireland's standing in international research rankings. Recent decades have also seen great improvements in university teaching, laboratory, library and sporting facilities.

And finally to return to the point I made about the public understanding of science at the start of this article, we could expect to produce a much more scientifically literate public if science and mathematics was taught at first and second level using the tried and tested guided-learning methods rather than the new minimal-guidance methods.

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Kitchen Chemistry: history and development

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History: Pre-Kitchen Chemistry

In 1998 I was given the opportunity to attend an EPSRC course, run at Techniquest in Cardiff, to train EPSRC funded researchers to present their research to non-specialist audiences. Soon after this the EPSRC put out a call for a pilot programme "Partnerships for Public Understanding". Having recently been on the training course I already had some ideas, so I applied.

My proposal was to develop and put on three demonstration lectures on aspects of physical chemistry research. This was to be done over a period of three years. My target audience was interested adults, specifically Women's Institute (WI) groups. This meant that the demonstrations had to be sufficiently portable to be transported around in a car. I also applied for all my audio-visual requirements as the plan was to use a camera and projector to enable small-scale experiments to be projected.

Needless to say my application was successful and towards the end of the three-year period I was able to apply for a second grant, on the same basis. The only small change was that the name of the scheme had changed to Partnerships for Public Awareness. My second application led to another the development and performance of another three demonstration lectures over the next three years.

One of the conditions of the grant programme was that the communication should be of EPSRC-funded research, but I was starting to look further than just demonstration lectures connected, however tenuously, to my research. As I am a musician, and a physicist (physical chemist actually) it was natural for me to produce a presentation which I called "The Sound of Science". This was a lecture about sound and musical instruments with me playing a variety of home-made instruments, leading up to a tune on the trombone as a grand finale.

Development

Kitchen Chemistry itself came about through contact with Scifest Africa: South Africa's National Science Festival.[1] In 2006 I had started to collaborate with Prof. Mike Cook, a colleague at UEA, on studies of the photophysics of phthalocyanines.[2,3] Prof. Cook was also collaborating with Prof. Tebello Nyokong from Rhodes University in South Africa. Prof. Nyokong learned of my demonstration lectures when we met at a conference. At the time she was on the Advisory Committee of the National Science Festival – Scifest Africa – and invited me to take part.

I performed at Scifest in 2008 and 2009 using the demonstration lectures developed with the EPSRC grant to show aspects of my research. The then Director of Scifest Africa, Anja Fourie, encouraged me to develop a chemistry show using readily available materials and unsophisticated equipment. This took a lot of inspiration from Lorelly Wilson's "Chemistry with Cabbage"[4] and other science shows that I had seen.

I returned to Scifest Africa in 2010 with Kitchen Chemistry, and not only performed it at the science festival, but also on tours of the Western Cape funded by the Embassy of the Kingdom of the Netherlands in South Africa. The Systemic Extra-Mural Education Development and Support (SEEDS) project was made up of eleven different partners, each with different interventions in rural and township schools throughout the Western Cape, over a four year period.[5,6]

In 2013 I was awarded a sabbatical from teaching and from early January until mid-April I toured South Africa giving shows and workshops in schools and science centres. Not only was I able to demonstrate directly to learners, I had the opportunity to train both educators and science centre staff. During the 100 days I was there, which included Scifest, I was involved in over 120 events and drove over 11,000 km (predominantly on my own). The shows were not just Kitchen Chemistry; I also had a couple of physics demonstration lectures ("The Sound of

Science" and "Lasers: the light fantastic") along with a version of the Royal Society of Chemistry's Spectroscopy in a Suitcase.[7]

Figure 1: The kitchen chemist

Kitchen Chemistry

The original Kitchen Chemistry show itself is made up of a number of different demonstrations linked by a narrative about what a chemist might end up doing. The first part serves to illustrate that the molecules a chemist works with are very small, but they influence the properties of the matter around us. From there we look at simple colour changes to indicate something about the nature or contents of a solution. Where possible, one or more new substances are made, and then we show how materials can be decomposed into their components. The individual demonstrations are broken down as follows:

Cartesian Diver

To attract the audience's attention and get them a little off balance to start with, I have a Cartesian Diver in a 2 L soda bottle. I divide the audience in two and each half has an opportunity to "push" the diver to the bottom of the bottle using their minds alone. Of course, the first group does not manage, where the second group does. If appropriate I explain the principle of action, or simply suggest that it might be a good question for later.

Number of molecules

To get across the mind-boggling size of the number of molecules in my Cartesian Diver bottle I have a series of laminated cards which make up the number. I invite members of the audience to join me on stage to hold up the cards, and make a play of how big the number is.

Newspaper ripping

Having established that molecules are very small, we then see that their size and shape dictates the properties of materials around us. To do this I use a newspaper, or any other sheet of paper. In one direction a tear is neat and relatively clean, as the fibres in the paper are aligned in the process of making the paper. A tear in the perpendicular direction results in a much more ragged tear, and the observation may be made that the tear is actually directed along the fibres.

Dissolution

I then usually move on to a "magic trick" that I have been practising. I tell the audience that I have been trying to make people disappear, but when I do, they do not return (at least not uninjured). So what I do instead is show how I practise, with salt. Having made a big show with magical "passes", I take a glass of water and dissolve the salt.

Evaporation

The salt has dissolved and not gone away, so this is the time to talk about evaporation. If we left the water for long enough the salt could be recovered as the water will evaporate. This I demonstrate using expanded polystyrene balls as "water" and coloured solid polystyrene balls as "salt". The expanded polystyrene may be blown out (and a show made of an imaginary piece of polystyrene being stuck in one's mouth).

Dissolution

I continue the dissolution theme by showing that expanded polystyrene may be "dissolved" in acetone. It might be possible to use nail polish remover for this, but the high water content of some formulations prevents them from working. I like to use long thin polystyrene sheets for this. The length means that the effect is very impressive.

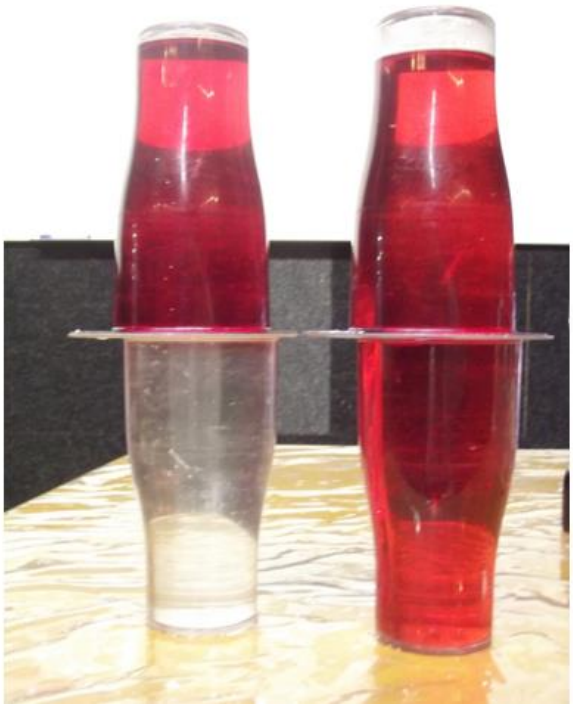

Figure 2: The final state of the density demonstration

Density – water and air

After a short description of the particulate nature of solids, liquids and gases there is a demonstration of the effect of density using hot (coloured) and cold (not coloured) water. Again, I make a great deal of the need to turn one of the glasses upside down on the other, until two offset CDs are used to make a lid / seal that enables one glass to be inverted and then when slid together they join the two glasses. A good example of the final state of this demonstration can be seen in **Error! Reference source not found.**.

The same effect can be obtained with a bag of air. The best bags to use are thin, crinkly bin liners. The air inside can be warmed above a toaster. Care must be taken to ensure that the bag does not melt or drop into the toaster. This can be done with large black bin bags but it will take considerably longer to fill than a smaller bin liner. It is good practice to trim excess plastic from the bottom and add some tape to the opening to weight it a little. This helps to prevent the bag inverting.

Indicators – vinegar and washing soda

Many coloured materials act as acid-base indicators. One of the best is red cabbage water, but this can be difficult to keep for long periods without biology making its presence felt. Instead I tend to choose fruit teas such as blackcurrant, cranberry etc. as they may be stored dry and made up on site. The active ingredient in all of these are anthocyanins, which turn green in a basic solution, purple at neutral pH and pink when acidic.

My chosen base is washing soda (sodium carbonate) and the acid is distilled, or spirit vinegar, which is colourless. The absence of colour in the vinegar enables the colour changes to be observed more readily.

Indicators – milk of magnesia

I then use Milk of Magnesia (a suspension of magnesium hydroxide) to demonstrate the use of an indicator. I explain that we might ask whether this material is acidic or basic. The milky solution when a little milk of magnesia is added to water turns the indicator green, so it can be seen to be a basic (alkaline) mixture.

This demonstration may also be used to demonstrate equilibria, because when acid is added the mixture turns the indicator back to pink. The concentration of dissolved hydroxide ions has thus gone down, which results in more magnesium hydroxide dissolving and over time the indicator regains its green colour. This will keep happening on addition of acid until all the solid has dissolved. This is a process which I liken to using up the charge in a battery.

Indicators – iodine starch and vitamin C

Not all indicators need to be highly coloured. A few drops of tincture of iodine in water produces a pale yellow solution. When starch indicator is added to this a deep blue colour forms. The starch indicator should be prepared in advance. I take a small amount (half a teaspoon) of cornflour and pour a small amount of boiling water onto it. I then boil that for a while. At home I do it in the microwave, and at a venue I would mix it in a polycarbonate glass and put the glass in a kettle that is one third full of water and let that boil (with the lid open) for a little while.

Having made the deep blue colour, addition of vitamin C will remove the colour. The vitamin C is an anti-oxidant, or reducing agent. It reduces the iodine to iodide. This is a quantitative reaction and can be used for analysing the amount of vitamin C in a solution. This was the basis of the Royal Society of Chemistry's global experiment in 2013.[8]

Water into wine

At this point I usually step away from the readily available chemicals and do a classic "Water into Wine" demonstration. I pour myself a large "gin" from a suitably labelled bottle, then explain how I was not meant to drink hard liquor on stage, so I pour it into another glass to turn it into "juice". Then it occurs to me that that white wine is not hard liquor so by pouring into a third glass I produce some white wine. I go to drink this (but do not, of course) and realise that it should be chilled, so I decide that red wine can be drunk at room temperature, and produce this by pouring into another glass. Before I get to drink that I "remember" that I should not be drinking alcohol as I have to drive, so take my bottle and a final glass, and produce some "milk".

The mixture in the bottle is water, phenolphthalein and salt. In the first glass I have nothing (gin), the second glass contains a few drops of sodium carbonate solution to turn the phenolphthalein pink (juice); the next glass has a few drops of concentrated iron(III) chloride, which is acidic (to remove the colour of the phenolphthalein) and yellow (white wine); the next glass has some ammonium thiocyanate, which reacts with the iron to produce a deep red colour. For my "milk" I have a few drops of silver nitrate solution in the glass, which reacts with the sodium chloride in the gin bottle. It is best to use wine glasses for this as the liquid tends to be disguised by the glass where the bowl joins the stem.

Holey bottle

I then go to drink from a bottle, which I "discover" has two skewers stuck through it. The audience is asked to predict what will happen when the skewers are removed. I then proceed to do that and explain that everything is balanced, air pressure, water pressure etc. By opening the lid of the bottle very satisfying streams of water can be produced. I have found the key to making this successful is to have the holes at the same height in the bottle. It does mean that the skewers have to be distorted a little when setting the bottle up, but bamboo kebab skewers are sufficiently flexible, especially if they have been immersed in water for a while.

Three cup trick

Finally I get my drink of water, but I use three identical polystyrene cups for this. One has been prepared with some super-absorber (sodium polyacrylate). This I usually buy from a garden centre. It is slightly slower to absorb water than the material found in nappies, but much easier to handle and less hazardous: the crystals in nappies are very fine and easy to inhale.

This I frame as a test of the power of observation of the audience members. I ensure that they know where some water is to start with, then proceed to swap cups round. Having done this I ask the audience which cup contains the water. I generally pour the water into the cup with the absorber for the third set of swaps. I can prolong this sufficiently that the water has been absorbed nicely and I am careful to say that the water does not "come out" of the cup.

This can be made very theatrical but I always try to make the point that not only should a scientist be able to make accurate observations, but they should also be very careful with language. When I said the water did not "come out" of the cup, it did not mean that the water was no longer in the cup.

New material

The absorbent material is a new material made by chemists, so at this point I generally make a new material. If the washing soda (sodium carbonate) solution is nice and clear it may be added to a solution of Epsom salts, at which point it forms a precipitate. The milky appearance of this mixture may be linked back to the milk of magnesia. Both are milky because of suspended solids.

If it is possible to get some borax, another new material may be made by adding borax to

PVA glue. I generally dilute the glue with some water and emphasis how runny it is. Then add a few drops of a borax solution to produce slime.

Fire extinguisher

Having put some things together to make new materials I then take a look at taking things apart. The first thing to try is sodium bicarbonate (bicarbonate of soda, sodium hydrogencarbonate) and acid. I explain that any carbonate material plus an acid will liberate carbon dioxide. Once the audience has confirmed for me that carbon dioxide is a gas I then ask them what we might observe. My analogy here is that if a solid (you) is sitting in a bath full of water (a liquid) and you made a gas, what would you observe? In this case the solid is the bicarbonate, the liquid is vinegar and we should see bubbles – which we do.

This gas can then be used to extinguish a candle, by pouring it from one container into another container where there is a lighted candle. This can be made more impressive by using an

Figure 3: The whoosh Bottle

intermediate container. We can explain this as carbon dioxide is denser than air so displaces air from the bottom of our containers. This can be related back to the earlier experiment with density.

Hydrogen peroxide with yeast

Another nice decomposition reaction is the so-called "elephant's toothpaste". I would normally have mixed some dried yeast with water prior to the start of the show and this is the source of the peroxidase enzymes that are required for this experiment. One can use blood, liver, celery, or some inorganic salts for this, but dried yeast is easy to store and transport. It also has the advantage that it will foam, which has been useful for me when I have forgotten to bring, or ask for, washing-up liquid, which helps to catch the bubbles of oxygen.

Not only is this a nice decomposition reaction, one can mention that we make hydrogen peroxide just by breathing, that it is breaking down slowly all the time and the yeast will simply speed up the reaction. At a suitable level one can use this to talk about enzymes and catalysts.

Whoosh bottle

I link this to the previous demonstration by noting that the "elephant's toothpaste" generates some heat during the reaction. We can thus use chemistry to make heat and one of the simplest ways is to burn a fuel. In this case we take a water cooler bottle and add some methylated or surgical spirits. I make sure that the inside is fully coated with liquid, give it a bit of a cuddle to warm up the bottle, and pour away any excess liquid. Always use a splint on a stick or a long barbeque lighter to light the bottle. The results of this experiment can be seen in **Error! Reference source not found.**.

These bottles can be expensive to get hold of. I have found that the water cooler companies are happy to supply bottles that they are taking out of service free-of-charge. These bottles would otherwise only have been sent for recycling.

Another thing to bear in mind here is that immediately after the demonstration the bottle has depleted its reserve of oxygen. If the experiment is repeated without refreshing the air in the bottle the alcohol will only burn at the neck of the bottle which will discolour and melt your bottle. (Yes, it has happened to me.)

Cornflour flame

The final flourish is a demonstration to show the energy there is in food. Cornflour may be blown out of a funnel and ignited with a variety of sources. My preference is to use a funnel on the end of a fairly rigid plastic tube. I blow in the end of the funnel and ignite the flame with a blowtorch as shown in **Error! Reference source not found.**.

Figure 4: The cornflour flame

There are many alternative ways of setting this up. For example the funnel can be clamped in place, as can the blowtorch and a stomp rocket pump may be used to expel the cornflour from the funnel. Instead of cornflour, custard powder may be used. This gives a markedly more intense flame, but the sugar and egg content of the custard powder means that it is slightly less straightforward to clear up.

Hints, tips and safety

Many of these demonstrations benefit from practice. Sometimes this can be done in a kitchen or lab, other times there is no substitute for trying it out in front of an audience. There are a number of hints and tips on the Kitchen Chemistry website,[9] and a forum where ideas and suggestions may be exchanged.

Please refer to the website[9] for details of safety advice. All the glasses I have referred to here are polycarbonate glasses from an internet supplier. Not only are these rigid, and stand up to heat, they

are also essentially unbreakable and, therefore, very useful when I am travelling. The large containers I use for the indicator experiments and other aqueous solutions are actually vases. I have been unable to refresh my stock from the internet, as only coloured or patterned vases seem to be available. In desperation I ordered in bulk from China, so if you would like some of these containers please contact me through the website.

Further development

There is now a second show titled Kitchen Chemistry: Second helpings, which has a different set of demonstrations but maintains the theme of readily obtainable materials and unsophisticated equipment**.** I am also gathering material and making preparation for there to be a third.

The variety of experiments that I have available now can be used to generate a selection for bespoke events. For example, I spent one week in January 2017 working with the British Council in France on their "Science in Schools" initiative. This was a combination of parts of the Kitchen Chemistry show and the RSC Global experiment[8], in order to allow the audience some hands-on experience of chemistry.

I have also used some of the demonstrations to put on a "Science of Santa"[10] demonstration lecture, with a colleague, Maxine Rushton. This was first performed as the Christmas Lecture for Young Children at the UEA in 2014, and was chosen to be part of the UK delegation for the "Science on Stage" conference which took place in London in 2015.

I have recently extended my work in Southern Africa. My Kitchen Chemistry Outreach Project in South Africa is helping me put to extend my activities to Johannesburg and the Durban area,

with the inaugural Umjikelezo We-Science festival[11,12] in 2017. I have also started visiting schools in the Maputo area of Mozambique with Kitchen Chemistry shows.

I am continually looking for opportunities to work with partners or to attract funding to extend the reach and impact of Kitchen Chemistry. The shows and teacher workshops are especially useful in areas of the world where specialised chemicals and well-equipped laboratories are not readily available.

If you think that something from Kitchen Chemistry could work for you, then please go ahead, adapt it for your needs, and use it. Very few of the demonstrations I do are original, I have merely adapted them to fit with my own requirements. Often the same demonstration may be used in a variety of ways to illustrate different points. If you need help then please contact me directly, or ask on the Forum.

If you would like Kitchen Chemistry to visit you, then please get in touch. I am happy to travel, and if we can come to some mutually convenient arrangement that fits around my day job, I will be happy to oblige.

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Website: http://www.kitchenchemistry.eu
Twitter: @Kitchen_Chem
Facebook:
http://www.facebook.com/KitchenChem

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Dr Ashworth was awarded both his BA in Chemistry and his DPhil from Oxford University. Later postdoctoral work was with Professor D.J. Nesbitt at JILA and later with Dr K.M. Evenson at NIST, both of which are in Boulder, Colorado. He was then awarded a Royal Society European Exchange Fellowship and an Alexander von Humboldt Stiftung Fellowship to study femtosecond dynamics at the newly established Max-Born Institute in Berlin.
The award of an EPSRC Advanced Fellowship in 1996 allowed him to return to England. The first part of the Fellowship was held in the School of Chemistry at Bristol University. Dr Ashworth was appointed to a post at the UEA in 1999 but chose to transfer the remainder of his Advanced Fellowship and became a Lecturer in 2001. He received the UEA Excellence in Teaching award in 2002.
Although his research career has concentrated on high resolution spectroscopy, and spectroscopy applied to atmospheric chemistry, using a number of laser techniques, he is now much more involved with the communication of science.

Over the years has won a number of grants for his communication activities. In 2009 he was awarded a CUE East Individual Award for Engagement. He has recently finished a term serving on the Advisory Committee of Scifest Africa.

The Central Role of (Photo)Electrochemistry in Renewable Energy Conversion, Storage and Supply-on-Demand

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Introduction

Endlessly abundant renewable sources of clean energy, such as solar, wind, hydroelectric or geothermal, are available to us as alternative power sources to our environmentally-destructive use of burning fossil fuels. Technology is urgently required to convert these renewable sources of energy into easily accessible usable forms of power, such as electricity and fuel.

Renewable energy is produced **intermittently**. Many factors impact the total amount of renewable energy available to us at any particular time such as:

- the time of day, *i.e.*, maximum solar power generation at noon, but none at night,
- local weather conditions on any particular day, *e.g.*, a bright, windy day *versus* a cloudy, calm day, and
- the seasons.

Certain geographical regions are better suited to particular types of renewable energy generation (solar in Australia, wind in Ireland, geothermal in Iceland, *etc.*). This is very clear with regards to which parts of the world are most suited to harnessing solar energy (Figure 1A).

There is often a mismatch between when renewable energy is generated most efficiently *versus* when it is most needed (Figure 1B). To overcome this mismatch, a process known as "**peak shaving**" is necessary (Figure 1C). Simply put, when excess energy is produced by renewables, beyond that required by the power grid at that moment, this excess energy should be stored. Later, when renewable energy is not meeting the demands of the power grid, the stored energy is utilized. In this manner, maximum use of the renewable energy produced is achieved and a stable power grid based solely on renewable sources becomes a realistic possibility.

Thus, efficient methods of converting and storing renewable energy for later use at different geographical sites are required. This stored renewable energy must be supplied on demand in an efficient, cost-effective manner, either directly as electricity or as a fuel, to have real practical benefits and compete with existing fossil fuels.

In this article, I detail how electrochemistry and the sub-discipline of photoelectrochemistry can help us reach these ambitious, but critically important, goals.

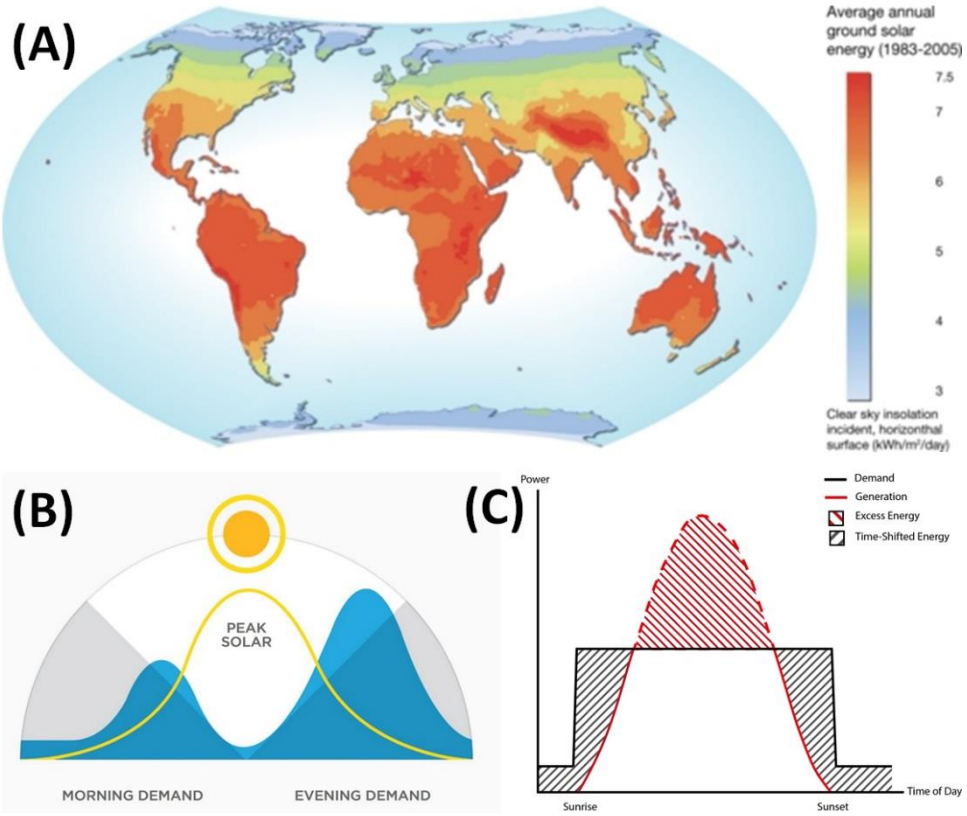

Figure 1. (A) The potential to produce solar energy is not spread evenly over the globe, certain regions such as Australia, Africa and South America are more geographically suited to this type of renewable energy (Solar potential worldwide. Image credit Hugo Ahlenius, UNEP/GRID-Arendal; http://www.grida.no/resources/7308). (B) The production of energy from a renewable source (such as solar energy) may not match exactly the time of day it is needed most. (C) "Peak shaving" involves storing energy produced from intermittent sources, such as most renewables, when excess is created, and then using that stored energy at a later time when demand is high.

The Basics of Electrochemistry

Electrochemistry is the study of the relationship between electrical energy and chemical change, and involves either:

- chemical change leading to the output of electrical energy from an electrochemical system, or
- chemical change due to the input of electrical energy into an electrochemical system.

An **electrochemical cell** typically comprises two electrodes immersed in an electrolyte solution and connected to each other externally by a wire in a closed-circuit. The electrodes and external wire are excellent electron conductors. The electrolyte solution contains an electrolyte salt dissociated into its constituent ions to conduct charge, and chemical species that are redox active, *i.e.* capable of reversible oxidation and reduction. Many different configurations of electrochemical cell are possible, for example, each electrode can be immersed in different compartments with separate electrolyte solutions. However, both compartments must be connected in some manner to permit the free movement of ions to maintain electrical neutrality in solution (*e.g.*, using an ion-conductive membrane or salt-bridge).

During an **electrochemical reaction**, one redox couple is reduced at the electrode known as the **cathode**, and another redox couple is oxidized at the second electrode, known as the **anode**.

Broadly, two types of electrochemical cell can be defined:

- a **Galvanic cell**, involving chemical change for a spontaneous, thermodynamically downhill electrochemical reaction, with a negative Gibbs free energy change (ΔG), leading to electrical energy output (Figure 2A), and
- an **electrolytic cell**, involving chemical change for a non-spontaneous, thermodynamically uphill electrochemical reaction, with a positive ΔG, requiring input of electrical energy (Figure 2B).

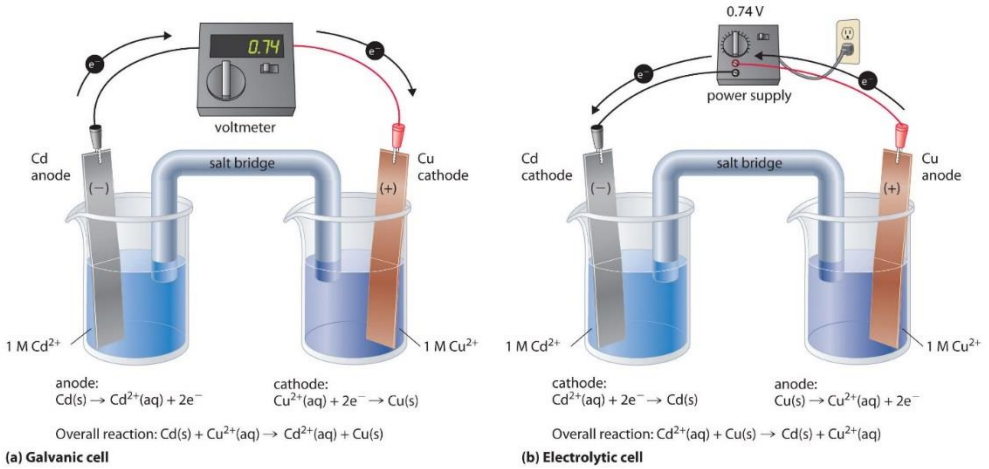

Figure 2. Electrochemical operation of (A) a Galvanic cell and (B) an electrolytic cell. To re-iterate, a Galvanic cell can be used as a power source to do work, whereas an electrolytic cell requires external power to operate. Image from Martin Silberberg, Principles of General Chemistry, 1st edition, McGraw-Hill Education.

Photoelectrochemical Devices to Convert Solar Energy

Photoelectrochemistry is the study of the interaction of light with electrochemical systems and plays a key role in the **conversion** of solar energy:

- to electricity using electrochemical photovoltaic technology, and
- to chemical fuels (known as "solar fuels") using photoelectrolytic cells.

A **photoelectrochemical cell** typically comprises a light-responsive photoelectrode and a non-light-sensitive counter electrode. Both are immersed in either the same, or separate, electrolyte solutions and connected to each other externally by a wire in a closed-circuit. If separate electrolyte solutions are employed then both compartments must be connected in some manner, such as by using an ion permeable membrane, to permit the free movement of ions to maintain electrical neutrality in solution. A huge variety of photoelectrodes have been developed, with the light active element normally being a semiconductor or dye-sensitized semiconductor. By absorbing energy from light, the photoelectrode can drive a non-spontaneous, thermodynamically-uphill electrochemical reaction, *e.g.*, the oxidation of a redox species.

Broadly, two types of photoelectrochemical cell have been developed: **electrochemical photovoltaic cells** and **photoelectrolytic cells**. Upon illumination, electrochemical photovoltaic cells recycle a redox active species between the photoelectrode and the counter electrode in solution. The potential difference between the photoelectrode and counter electrode, or **photovoltage**, causes electrons released at the photoelectrode to flow along the external wire to the counter electrode, generating an electric current. The reverse spontaneous, thermodynamically-downhill reduction reaction subsequently takes place at the counter electrode. Thus, in a major difference with Galvanic cells for example, the redox species is recycled and electricity is generated upon illumination with light without net chemical change in solution.

The most famous example of an electrochemical photovoltaic cell is the dye sensitized solar cell (DSSC), see Figure 3A. Upon illumination, in an ideal photoelectrolytic cell, the electrons released due to the light-driven oxidation of a chemical species at the photoelectrode are used to spontaneously reduce a different chemical species at the counter electrode, see Figure 3B. The counter electrode may be in either the same or another compartment. Often the kinetics of purely light-driven photoelectrolytic reactions are sluggish. Therefore, an external voltage from an input of electrical energy is applied to assist. This external voltage can be supplied by a photovoltaic (PV) cell. Photoeleectrolytic cells may also be designed whereby both the cathode and anode are non-light sensitive, but all of the power required to drive the thermodynamically-uphill electrochemical reaction is provided by a PV cell. Typically, photoelectrolytic cells are used to split water to hydrogen gas (H_2) and oxygen, with the H_2 stored

as a "solar fuel". In addition, photoelectrolytic cells are under major investigation as a route to reducing CO_2 in an environmentally-friendly manner to useful chemicals such as formic acid, methanol, ethylene and methane, some of which can act as solar fuels or feedstock molecules for the pharmaceutical industry.

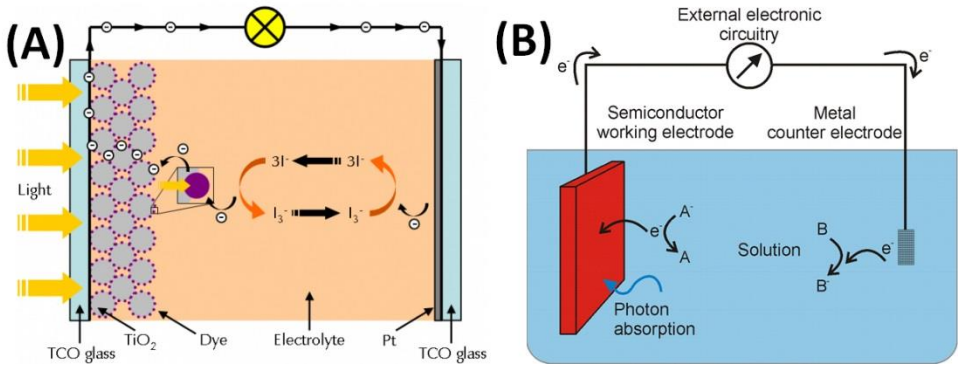

Figure 3. (A) Schematic of a dye-sensitized solar cell (DSSC), an example of an electrochemical photovoltaic cell. The redox couple I^-/I_3^- is recycled between the photoelectrode, usually dye-sensitized TiO_2 on a transparent conductive oxide (TCO) glass electrode, and the non-light sensitive counter electrode, usually TCO glass coated in catalytic platinum nanoparticles. Image from https://www.gamry.com/application-notes/physechem/dssc-dye-sensitized-solar-cells/. (B) Schematic of simple photoelectrolytic cell where energy from light is absorbed at the semiconductor working electrode to drive a thermodynamically uphill redox reaction (A^- is oxidized to A with an electron released). The electron released by A^- travels around the external circuit to reduce a different species at the counter electrode (B is reduced to B^-). Image from http://knowledge.electrochem.org/encycl/art-p06-photoel.htm.

Electrochemical Devices to Store Renewably Generated Electricity

Electrochemistry plays in a key role in the **storage** of electricity generated by any renewable source (wind, solar, hydroelectric, geothermal, *etc.*):

- by charging batteries such as lithium-ion (Li-ion) and redox flow batteries, and
- by reducing a chemical species such as water or carbon dioxide (CO_2) using electrolytic cells.

A **battery** is an assembly of electrochemical cells engineered for use in devices. A **primary battery**, constructed from Galvanic electrochemical cells, such as the alkaline zinc-manganese dioxide battery, will cease working once the chemical energy stored in the cell is fully converted to electrical energy and "discharged". Thus, primary batteries are not suitable for applications in storing renewably generated electricity as they cannot be "charged" again after a single use. Much more relevant, however, are **secondary batteries** that can be charged by using an external power source to drive the electrochemical reaction in the cell in the opposite non-spontaneous direction, *i.e.*, effectively operating as a Galvanic cell in "discharging mode" and an electrolytic cell in "charging mode". Examples of secondary batteries include the lead-acid battery, used in cars, and **lithium-ion (Li-ion) batteries** which are much more lightweight and used to power portable electronics.

Scale-up of batteries for large-scale storage of renewable energy is essential. Recently, Tesla built the largest Li-ion battery complex in the world, connected to a wind farm in southern Australia.

One class of batteries ideally designed for large-scale storage of renewable energy are **redox flow batteries (RBFs)**. The distinguishing feature of RBFs is that the electrolyte is stored in external tanks or reservoirs and circulated through the battery during charging and discharging events. In contrast, for traditional batteries, all of the electrolyte remains within the cell at all times. The electrochemical operation of a generic RFB is described in Figure 4. RBFs have the ability to independently tune their power capacity and energy storage capacity. The power capacity can be increased by increasing the electroactive surface area of each electrode, the number of electrodes in each "cell stack", or the number of stacks in the RBF. Meanwhile, the energy storage capacity can be increased by increasing the volume of electrolyte stored externally in the reservoir tanks and by maximising the concentration of the redox species in the electrolyte solutions. Thus, in time, extremely large RBFs will have the potential to be charged by electricity generated renewably and store enough chemical energy to supply entire towns with

electrical energy in a controlled non-intermittent fashion. The field of RBFs is currently extremely active with iron-chromium, all vanadium, vanadium-bromide, and vanadium-O_2 RBFs among those most researched. Also, non-aqueous organic RBFs have shown promise.

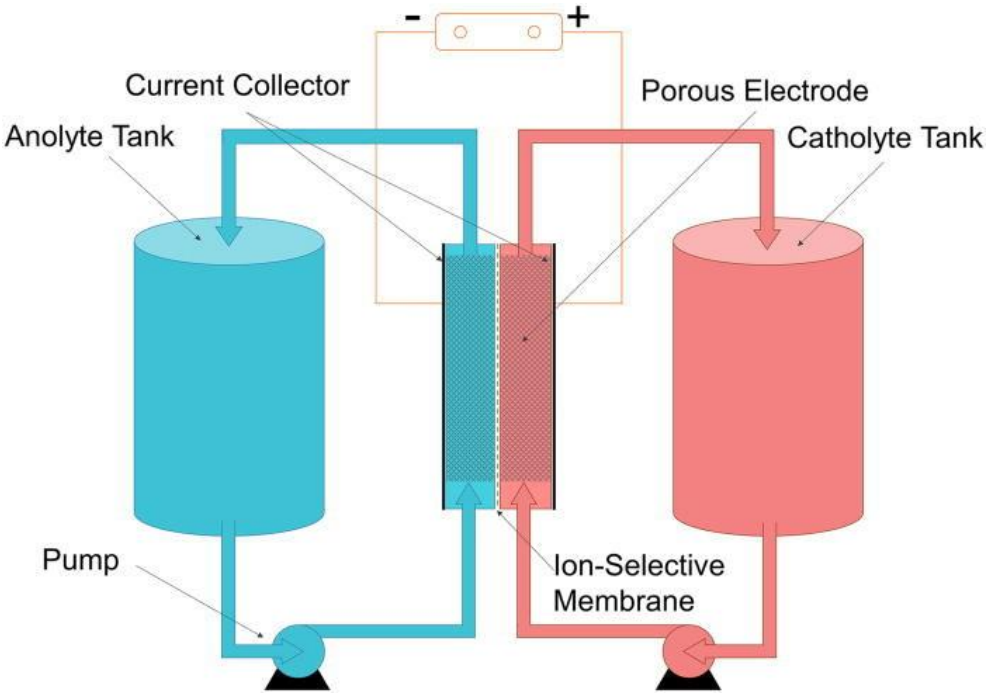

Figure 4: Electrochemical operation of a generic redox flow battery (RFB). A RBF consists of two electrodes (or current collectors), typically made from carbon felt, connected to each other externally in a closed-circuit. A "catholyte" electrolyte circulates in the cathodic side of the RBF and an "anolyte" electrolyte circulates in the anodic side of the RBF. The catholyte and anolyte are separated by an ion selective membrane. During charging, by using an external power source to drive the electrochemical reaction in the RBF in the non-spontaneous, thermodynamically uphill direction, the redox species in the catholyte is reduced and the other redox species in the anolyte is oxidized. Electroneutrality is maintained by movement of ions through the membrane connecting both electrolyte solutions. The redox species are pumped out of the RBF into external reservoirs to prevent self-discharge when the power supply is switched off. To discharge, the stored "charged" electrolytes are re-introduced into the RBF and instantly the opposite spontaneous, thermodynamically downhill electrochemical reaction takes place and generates electricity. Image by Colintheone - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=59002803.

Electrochemical Devices to Supply Renewable Energy on Demand

Electrochemistry plays a key role in the **supply-on-demand** of electricity:

- by discharging batteries, previously charged by electricity generated renewably, and
- by oxidizing chemicals in fuel cells. These fuels, such as hydrogen gas (H_2) or alcohols, were generated renewably previously using either photoelectrolytic or electrolytic cells.

A **fuel cell** is similar to a Galvanic cell in that the electrochemical reaction that takes place occurs spontaneously, and chemical energy is converted to electricity. However, in a fuel cell, the fuel, for example H_2 gas or methanol, is fed continuously into the device. This means that as long as fuel is being introduced into the cell then electricity will flow. The H_2 fuel cell is a good example, the electrochemical operation of which is outlined in Figure 5. Fuel cells are now poised to find major applications in electric vehicles powered by clean energy. Instead of petrol or diesel, the car is fuelled with H_2 gas. The H_2 gas is oxidized (or combusted) to produce electricity and water vapour as the only products!

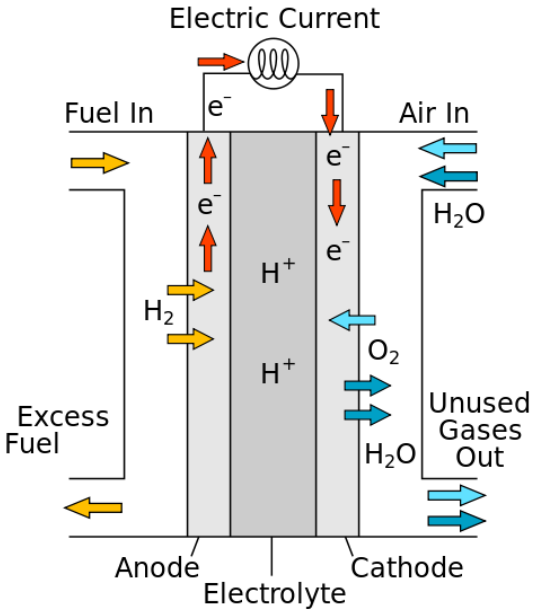

Figure 5. Electrochemical operation of a H_2 fuel cell. H_2 gas is introduced continuously at the anode and air is introduced continuously at the cathode. H_2 is oxidized at the anode, producing a flow of electrons around the external circuit (which can be used to power a device such as the motor of a car) and protons. The protons move from the anodic chamber to the cathodic chamber through an ion selective membrane. At the cathode, O_2 in the air is reduced in the presence of these protons creating water vapour. Image By R.Dervisoglu - Own work, based on http://en.wikipedia.org/wiki/File:Solid_oxide_fuel_cell.svg, Public Domain, https://commons.wikimedia.org/w/index.php?curid=19314043

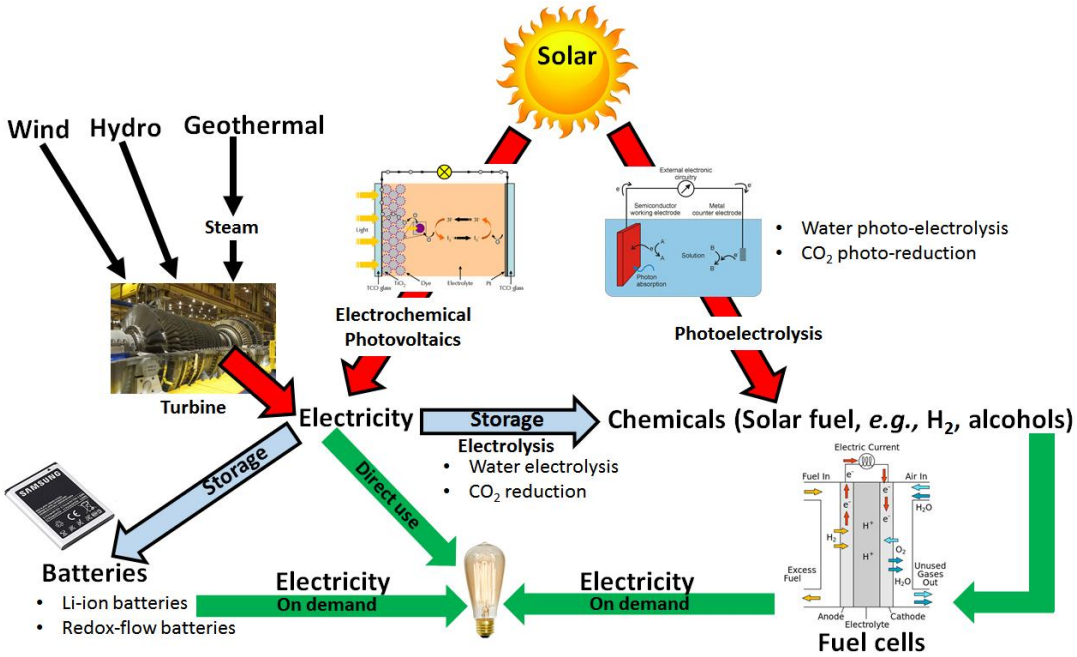

Figure 6. Schematic of the "big picture" detailing (i) how renewable sources of clean energy, e.g., wind, hydroelectric, geothermal, solar etc., are converted to electricity or directly to chemicals (red arrows), (ii) how the electricity is stored for later use (blue arrows), and (iii) how the stored electricity and "solar fuel" is used to generate power on demand (green arrows). At each step an electrochemical or photoelectrochemical device plays a central role.

Final overview

To re-cap:

- In an electrochemical photovoltaic cell, light energy is converted to electrical energy.

- In a photoelectrolytic cell, light energy is converted to chemical energy.
- In an electrolytic cell, electrical energy is converted to chemical energy.
- In a secondary battery, electrical energy is converted to chemical energy when charging and *vice versa* during discharging.
- In a fuel cell, chemical energy is converted to electrical energy.

Each of these (photo)electrochemical systems play vital roles in the conversion, storage and supply-on-demand of renewable energy. The interplay between all of these devices to create the infrastructure necessary to harness and use clean energy is summarised in Figure 6 above.

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http://knowledge.electrochem.org/encycl/art-p06-photoel.htm.

https://en.wikipedia.org/wiki/Flow_battery

https://en.wikipedia.org/wiki/Fuel_cell

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Dr Micheál D. Scanlon is a physical chemist who specializes in electrochemistry. Currently he is a Lecturer in the Department of Chemical Sciences at the University of Limerick (UL) in Ireland. He was awarded a European Research Council (ERC) Starting Grant in 2016 and is establishing his new research group in the Bernal Institute at UL. Previously, through a Science Foundation Ireland Starting Investigator Research Grant (SFI SIRG), he began his independent research career in the Chemistry Department at University College Cork (UCC) in Ireland.

Dr Scanlon was a postdoctoral researcher in the group of Prof. Hubert H. Girault at École Polytechnique de Lausanne (EPFL) in Switzerland and Prof. Edmond Magner at the University of Limerick (UL) in Ireland. He completed his PhD studies under the supervision of Prof. Damien W.M. Arrigan (now Curtin University, Perth, Australia) at the Tyndall National Institute in Cork and has a BSc. in Chemistry from UCC.

Diary

2018

7th BASF Summer School for Chemistry Teachers
26th June and 27th June
Eureka Centre University College Cork.
Contact: d.kennedy@ucc.ie

*****

SMEC 2018
Connecting Research, Policy and Practice in STEM Education
26 June
St. Patrick's College, DCU
https://www.dcu.ie/smec/smec-2018.shtml

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Chemistry Demonstration Workshop
4-6 July
University of Limerick
Contact: **SSPCOutreach@ul.ie**

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25th International Conference on Chemical Education, ICCE
10-14th July, University of Sydney, Australia
www.icce2018.org/

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25th Biennial Conference on Chemical Education
July 29 – August 2, University of Notre Dame in South Bend, IN, USA
www.bcce2018.org

*****

14th European Conference on Research in Chemical Education, ECRICE
This will be held in Warsaw, Poland from 2-6 September. The theme is: **"Educational innovations and teachers' needs"**
www.ecrice2018.pl/

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ChemEd-Ireland
'Bridging the gap'
20 Oct.
Trinity College. Dublin
Contact: john.odonoghue@tcd.ie

2019

International Year of the Periodic Table, IYPT 2019

ISTA Annual Conference
12th - 14th April
DCU, St Patrick's Campus, Drumcondra & All Hallows College
www.ista.ie

*****

ChemEd-Ireland 2019
19th Oct. (tbc)
Dublin Institute of Technology
Claire.mcdonnell@dit.ie

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If you know of any relevant conferences or events of interest to chemistry teachers, please send in details to: peter.childs@ul.ie

What makes a successful chemistry school?

Peter E. Childs, Megan McCarthy and Lisa Waldron
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Peter.childs@ul.ie

Abstract

In Ireland senior cycle (Leaving Certificate, LC) Biology is almost four times as popular as Chemistry and Physics. Around 15% of the senior cycle cohort study LC Chemistry each year, but the take-up of Chemistry varies widely from one school to another. All students study the same science course in the junior cycle and so nominally have a common background entering the senior cycle. We were interested to investigate why some schools are more successful than others in attracting students to study Chemistry. By identifying contributing factors in successful schools then this might allow us to transfer them to less successful schools. This paper reports two studies, done as final year research projects by science education students. One was done in 2009 (LW) and the other in 2014 (MMcC), to answer this question: 'What makes a successful Chemistry school?' Schools where the take-up of Chemistry was significantly above the national average were identified. We termed these schools 'successful'. In 2009 we sent questionnaires to 35 successful schools in the whole country, and received 12 replies. In 2014 we identified 15 pairs of similar schools in one province of the country: one with above average enrolment for LC Chemistry and the other below average, keeping other factors the same. Questionnaires were sent to all the 15 pairs, 30 schools in total, to identify factors common to successful schools and not found in less successful schools. Results from 8 complete pairs (16 schools, 53%) were returned and analysed.

From the 2014 results we could identify common factors in the successful schools, similar to but more extensive than from the 2009 study. The data enabled us to produce a profile of a successful Irish second-level school in relation to Chemistry enrolment. These factors influence the view students have of science and particularly whether they want to study the physical sciences in the senior cycle.
This study gives ideas for helping schools increase their take-up of Chemistry. Irish schools offer the same curriculum but can vary widely in size, type, style, location, resources and intake, thus the actual educational experience received by students can thus vary widely.

Introduction

This project was initiated by the fact that in Ireland senior cycle Biology is almost four times as popular as Chemistry and Physics. Although around 15% of the senior cycle cohort study Chemistry each year, the take-up of Chemistry varies widely from one school to another. Some schools can run two LC Chemistry classes and similar schools can only manage to recruit a handful of Chemistry students. Chemistry is offered in just over 76% of schools and around 14% of students do not have the option of studying Chemistry. (See Table 1) A similar situation applies to Physics, although the figures are worse for Physics than for Chemistry.

Table 1: Availability of the Main Leaving Certificate Sciences (2000/2001) *(Source: Task Force on Physical Sciences, 2002)*

	BIOLOGY	PHYSICS	CHEMISTRY
# schools offering subject	704	566	536
# LC students in schools offering subject	107,345	96,246	93,413
# schools not offering subject	23	161	191
# LC students in schools not offering subject	1,197	12,296	15,129
% LC students in schools not offering subject	1.1%	11.3%	13.9%

In Ireland all students study the same science course in the junior cycle and so nominally have a common background when they enter senior cycle, although science is not compulsory in the second level curriculum. Around 90% of JC students take Science, although more boys than girtls take it. The major imbalance in Ireland between Biology and the Physical Sciences has been a concern for many years and in 2000 resulted in a government Task Force on the Physical Sciences being set up to investigate the problem and make recommendations (Task Force, 2002) . Since then nothing significant has changed.

We were interested to investigate why some Irish schools are more successful than others in attracting students to study Chemistry. When this work was done the largest second-level school in the country did not offer LC Chemistry as a choice. By identifying contributing factors in successful schools this might allow us to transfer them to less successful schools and thus increase enrolment in the physical sciences. Over 75% of schools offer the Transtition Year Option (TYO), an optional year between the junior and senior cycles, where schools are free to be more innovative as they are not bound by a prescribed curriculum. This should should provide an additional opportunity for schools to promote the physical sciences.

Literature survey

Very little work has been done on why some schools are more successful than others in particular sciences, although there has been work on subject choice in Ireland (Smyth and Hannan, 2002). The main findings of this study were that schools that encourage take-up of senior cycle science:

- Have compulsory Junior Certificate Science (ibid, p.28,118)
- Have a flexible approach to subject choice (allow students to choose later) (ibid, p:105)
- Emphasise practical work and experimentation (ibid, p:236)
- Have teachers that take an active role in their own professional development: through participation in activities run by the Irish Science Teachers Association (ISTA) (ibid, p:237)

A similar study in the UK (Turp, 2008; Progression to post -16 Science, 2009) identified the following factors that promote the take-up of post-16 science:

- Curriculum continuity and planning to ensure that pupils make progress in their learning each year;
- Lively, experiential, colourful teaching of science in Key Stage 3 and (less so) in Key Stage 4;
- Teaching that challenges, asks questions, is relevant, meaningful and purposeful;
- A curriculum enriched by visits, visitors and projects that bring the world of science into the classroom; and
- Good resourcing, effectively used and targeted at identified priorities.

An Irish intervention project in the 1980s focused on encouraging girls' schools to take up Chemistry and Physics (O'Brien and Porter, 1994). This was never expanded beyond the 33 pilot schools although it showed some success. In 2017slightly more girls than boys now take LC Chemistry, althtough Biology is taken by many more girls than boys, and Physics by more boys than girls.

Our particular interest was in the uptake of Chemistry in the senior cycle and led to the following research questions:

RQ1. Why are some Irish schools more successful than others in encouraging students to take up Chemistry?

RQ2. Does chemistry take-up depend on school type (mixed or single sex), location (urban or rural) or size?

RQ3. Is it possible to identify a profile of a successful school?

Answers to these questions would be helpful in trying to increase enrolment in senior chemistry courses and might also have relevance to other countries. This is in accord with the stated aspirations of the new STEM Education Policy Plan (2017), which aims to achieve (among other aims):

- Increase by 20% the total students taking Chemistry, Physics, Technology and Engineering for Leaving Certificate.
- Increase by 40% the number of females taking STEM subjects for Leaving Certificate.

Methodology

Two studies were done to try and investigate the problem of low Chemistry take-up and answer our research questions. In each study the school enrolment figures for LC Chemistry, relative to the school's LC cohort, obtained from the State Examinations Commission, were used to identify successful schools i.e. schools which attracted much more than the average enrolment in Chemistry. Both studies were done by pre-service science teachers (PSSTs) for their final year projects (FRP), as part of their degree (Waldron, 2009 and McCarthy, 2014). Both students (LW and MMcC) were studying Physical Education and Chemistry. Schools are not all the same and differ in school type, gender (mixed or single-sex), size and location (rural versus urban),catchment etc.

a) Study 1

In this study (LW) identified 35 schools in Ireland (11 fee-paying, 24 state funded) which enrolled over 30% in LC chemistry, twice the national average (14%, 2009), although not every school offers Chemistry (536 out of 704 schools in 2000/1,

Table 1). The chemistry teacher in these schools was sent a questionnaire to identify what factors were present in the schools, having first validated and revised the questionnaire in a pilot study. 12 replies (34%) were received and analysed to identify common factors.

b) Study 2

This study (MMcC) was done 5 years later (2014) and focused only on schools in Munster, one province of Ireland, which contains a sizeable number of schools (over 200), which are fairly representative of the variety of schools in the whole country. From the enrolment figures relative to the LC cohort, matched pairs of schools were identified: they were classed as successful (above average) or unsuccessful (below average) and matched for school type, gender and location as closely as possible. Fee-paying and 'grinds' (which coach for the state examinations) schools were not included, as not being representative of the Irish school population. 15 matched pairs of schools were identified and the Chemistry teachers were sent a questionnaire based on that used in the first study. In total 8 complete pairs were returned (16 schools, 53%) and analysed to look for differences in the factors between successful and unsuccessful schools. (See Table 2 for the sample schools.)

Table 2: Characteristics of schools who responded in study 2

Code	Type	Location	Size of LC cohort	% chemistry
A1	**Mixed**	**City**	**83**	**22**
A2	Mixed	City	92	14
B1	**Mixed**	**Country**	**40**	**26**
B2	Mixed	Country	45	13
C1	**Mixed**	**City**	**190**	**27**
C2	Mixed	City	230	15
D1	**Mixed**	**City**	**95**	**34**
D2	Mixed	City	120	14
M1	**Male only**	**City**	**96**	**32**
M2	Male only	City	120	15
N1	Male only	Country	39	13
N2	**Male only**	**Country**	**50**	**30**
I1	**Female only**	**City**	**78**	**28**
I2	Female only	City	73	15
J1	Female only	Country	65	9
J2	**Female only**	**Country**	**60**	**33**

Some limitations of the two studies:

- Both studies had a small sample based on actual returns.
- The results were obtained only by means of a written questionnaire, which can produce bias or incorrect answers.
- The choice of criteria for successful or unsuccessful schools was arbitrary.
- Only the teachers were surveyed and not their students.

Ethical approval was obtained for the study. Each school was given a code and no individual schools or teachers were identified in the results.

Results

a) Study 1

Study 1 was more limited in scope and only successful schools were targeted, although all schools in the country were considered. The results are untypical of the school population as there was a much higher proportion of fee-paying schools (33%) in the successful sample than in the whole population (7%).

The following were found to be common characteristics of the successful schools:

- **Compulsory junior cycle Science.**
- **A flexible timetabling system at senior cycle to facilitate wide subject choice.**
- **An emphasis on practical work.**
- Outside resources used in teaching
- **At least one qualified Chemistry teacher taking junior cycle Science classes**
- **Three year allocation of Science teachers in junior cycle**
- **A tradition of Science in their school.**
- **Good facilities/resources**
- **Existence of Transition Year**
- **Availability of Laboratory Technicians**
- Involvement in external Science events such as BT Young Scientist and Science week
- Teachers who are actively involved in their professional development through attendance at in-service and active membership of ISTA.

The factors highlighted in bold are school-related factors; the others are teacher-related. These results are skewed by the large proportion of fee-paying schools in the sample, which are better resourced in all aspects: equipment, laboratories, technical help.

b) Study 2

This study only considered non-fee paying schools and so is more representative of the whole school population. For each of the questions, the number of successful and unsuccessful schools which gave positive answers were identified (see Table 3 for an example). This enabled us to see which factors were present in each type of school. For all factors, it was found that they were more represented in the successful than in the successful schools. For example when the question was: 'Is a science culture present in the school', Table 3 shows the

responses (successful school codes in bold.) All successful schools consider a science culture important and only one of the unsuccessful schools. This pattern of responses was repeated in all the questions.

Table 3: Is a science culture important in the school? (Bold = successful schools)

Is important	Not important
A1	B2
A2	M1
B1	J1
M2	D2
I1	C2
N2	I2
J2	N1
D1	
C1	

Table 4 below shows a summary of all the factors. In all cases many more of the successful schools identified that the factors were present than in the less successful schools. The differences were independent of the various school factors (RQ2). There is clearly a different profile for those schools were are successful in encouraging students to take senior cycle Chemistry and schools which are less successful. (RQ1) These data allow us to draw up a profile of a successful Chemistry school (RQ3).

Table 4: Summary of factors influencing take-up of Chemistry

Factor	No of successful schools where present (N=8)	No of less successful schools where factor present (N = 8)
Head of science	**6**	0
Science budget	**6**	0
3 laboratories	**7**	3
Use of outside resources	**8**	5
Science culture important	**8**	1
Timetabling Junior science (2 single, 1 double)	**7**	4
Non-mandatory experiments	**6**	1
TY compulsory	**7**	2
Science tradition in school	**8**	3
Science promotion	**8**	4
External competitions	**8**	3
JC science teachers qualified in chemistry	**27**	16

Nearly **all** these factors are school-related rather than teacher-related, supporting the findings from Study 1.

Discussion & conclusions

If subject choice only depended on the presence of a charismatic teacher in a school then it would be difficult to replicate. However, if the factors which promote the take-up of science, in our case Chemistry, are institutional or procedural, i.e. school-related, then these could be replicated in other schools. It would appear from our findings in Irish schools in both studies that most of the factors could be implemented in all schools, given the will and commitment of the management and science teachers. The two sets of results are in substantial agreement and allow us to draw up a profile of a school which is successful in encouraging students to take-up LC Chemistry. (we would imagine that the factors would be similar for Physics.)

A profile of a successful chemistry school:

- Compulsory junior cycle Science.
- Emphasis on practical work in junior cycle (JC) and senior cycle (LC) science – beyond the mandatory requirements.
- Use of outside resources in teaching.
- Many junior cycle science teachers qualified to teach Chemistry (o students meet Chemistry teachers in the junior cycle).
- A pro-science tradition in the school supported by the management.
- Good facilities and resources – especially laboratories.
- Compulsory Transition Year including science modules.
- Involvement in external science events e.g. science fairs.
- Teachers involved in CPD courses.
- Science promotion activities in the school.
- Proper timetabling of junior cycle science to allow for adequate laboratory usage.
- Head of Science/science coordinator.

Most of these factors are not specific to Ireland and are what one would expect for a school and science teachers who are trying to teach science in the best possible way and promote its uptake. Similar factors should also apply to the promotion of senior cycle Physics. A deliberate school policy to promote senior cycle science and provide adequate resources and encourage teacher CPD, should work to improve the take-up of senior cycle sciences, particularly Chemistry and Physics. In schools where laboratory technicians are available, mainly in fee-paying schools, this has a major impact on the way science is taught and the amount of practical work. The provision of laboratory technicians in schools is the subject of a long-running campaign by the ISTA. The importance of a positive school culture promoting science, from

the Principal downwards, cannot be over-estimated in its effect on strong enrolments in Chemistry and Physics. Most of the school-related factors flow out of and depend on this pro-science culture. Such schools also tend to recruit and keep enthusiastic and committed science teachers.

These were preliminary studies and raise a number of questions and an agenda for future work:

- Will a larger sample of schools replicate these findings?
- Which are the most important factors of the ones identified?
- Is it possible to increase Chemistry (or Physics) take-up by implementing some or all of the factors in schools where they are not present?
- Will a survey of junior cycle students identify the same or other factors encouraging them to take LC Chemistry (or Physics)?

Acknowledgements

We would like acknowledge the cooperation of the schools and teachers who returned questionnaires and the provision of school enrolment statistics by the Schools Examinations Commission.

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This paper is based on work done on their Final Year Projects by Lisa Waldron and Megan McCarthy and has been presented at ECRICE 2016 in Barcelona and NPSE 2018 in Florence.

□

Quotable Quotes

"In my school, the brightest boys did math and physics, the less bright did physics and chemistry, and the least bright did biology. I wanted to do math and physics, but my father made me do chemistry because he thought there would be no jobs for mathematicians."
Stephen Hawking

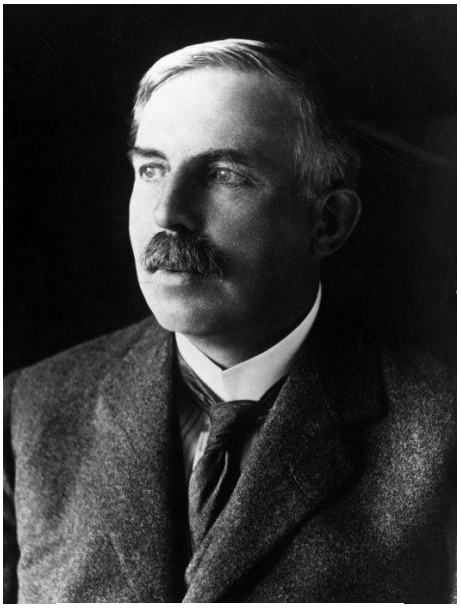
"Every time I sat in a chemistry lesson, I thought, 'What am I doing this for? I don't ever want to be in a job that involves a Bunsen burner.'"
Simon Cowell

"Chemistry has been termed by the physicist as the messy part of physics, but that is no reason why the physicists should be permitted to make a mess of chemistry when they invade it."
Frederick Soddy

Chemists you should know: #3

Ernest Lord Rutherford 30th August 1871 – 19th October 1937

Adrian J. Ryder tutorajr@gmail.com



Rutherford in the prime of life

Introduction: from plum pudding to the Bohr atom

Aware that the atom was composed of electrons and protons by 1900, scientists had varied theories on how they were organised. In 1904 J.J. Thomson suggested a 'plum pudding' atom, with the particles embedded somewhat like the fruit pieces in a plum pudding. This notion fought for acceptance until it was refuted by Ernest Rutherford's famous gold-leaf experiment, which showed a highly dense positive core taking up minuscule space. He suggested that the negative electrons spun around this nucleus somewhat in the manner of planets around the sun. Niels Bohr, working under Rutherford from 1912, adapted this notion to involve electrostatic forces leading to stable electron orbits in 1913 (the Bohr atom). This is still today the primary presentation of the atom to students. The third member of the atom, the neutron, does not appear until James Chadwick's work in 1932. In this essay the focus is on Ernest Rutherford's life and work.

Early life

New Zealand was discovered and populated by the Polynesians prior to 1300 AD, who became its indigenous Maori population, who unfortunately happily engaged themselves in tribal warfare and never united to become a nation. It was only in 1642 that the initial European visitor, Abel Tasman, the Dutch explorer, made landfall and having lost four sailors to a Maori war party decided not to land and sailed away, however claiming the islands for his country and naming them New Zealand. It was only when Captain James Cook, on his first voyage, arrived in 1769 and circumnavigated the lands making detailed maps that interest in the exotic area was aroused and sporadic adventurers, missionaries and traders began to arrive. The end of the third decade of the nineteenth century saw the beginning of the formal colonisation. The poster below shows an advertisement geared towards a Scottish grouping dated 1839.

FIRST SCOTTISH COLONY for New Zealand

That Fine Fast Sailing Teak-Built SHIP

BENCAL MERCHANT,

301 *Tons Register*—JOHN HEMERY, Commander,

Will Positively

SAIL FROM PORT-GLASGOW

For NEW ZEALAND,

With the first Body of Settlers

FROM SCOTLAND,

On FRIDAY, Oct. 25.

SINGLE WOMEN, going out as Servants to Cabin Passengers, or in charge of Married Emigrants, will receive a *Free Passage* on board of this Ship.

All Goods and Luggage must be forwarded by the 20th instant *at latest*, on which day the Ship will clear out.

For *Freight* (having room for dead Weight and Measurement Goods) and *Passage*, apply to

JOHN CRAWFORD,

24, QUEEN STREET.

New Zealand Land Co.'s Office,
Glasgow, 5th Oct. 1839.

J. Clark, Printer, Argyle Office.

© Copyright, People's Palace Museum, Glasgow Green

Printed by Ben Lyon Limited, 34A Robertson St., Glasgow G2 8DU

British crown officials had duped the Maori chiefs into accepting a treaty to allow such groups as colonists at Waitangi in 1840. European diseases and the importation of rifles and other guns saw the Maori decimated by disease, for which they had no immunity, and the inter-tribal warfare which became more lethal than ever. The imposition of British economics and a one-sided legal system, and the use of imported soldiers to quell sporadic uprisings against the colonists over the rest of the century, saw the Maori decimated and impoverished.

One early group of settlers from Scotland set sail on the 16th November 1842, on the sailing ship Phoeba, arriving in New Zealand on the 29th March 1843. Among the passengers was a George Rutherford from Dundee, a wheelwright engaged to set up a timber mill at Spring Water (now Brightwater), some thirteen miles south of Nelson (South Island), which had been set up in 1841. George (4th Nov 1804 – 1st May 1864) brought his family with him: his wife Barbara Adie (b. 1807), his children Andrew (1834), George (27th May 1837), James (24th Nov. 1838 – 1928), the father of the subject of this essay, Ernest, and John (21st August 1840 – 31st October 1923). Five more children, Jane (22nd June 1843), Barbara, William, Ann and Charles were born in New Zealand.

Over the years the family acquired a thirty-five acre farm growing flax but James also carried on his father's trade of wheelwright at the same time. On the 28th of April 1866, James married Martha Thompson (c. 1842 – 16th July 1935) from England, who had immigrated at the age of thirteen with her widowed mother in 1855. The couple produced a dozen children, five girls and seven boys, Ernest being the fourth, over the following years. The children were George (1867 -), Ellen Caroline (Chapman) (1869-), Alice Jane (Elliot) (1870-1910), Ernest (30th Aug. 1871 – 19th Oct. 1937), James Gordon (1872 -), Herbert (1874 – 1886) Drowned, Charles William (1875 – 1886) Drowned, Florence May (Streif) (1876 -), Ethel Rose (Sergal) (1877 -), Evelyn Maud (1878 -), Arthur Raymond (1881 -) and, Percy (1882 – 1883), who died of whooping cough aged 1 year 2 days.

Ernest attended the local primary school at Foxhill, and his school record is still available showing how he passed through two standards in one of his years there. His mother saved his first science text book with his name inscribed in it, that he had at the early age of ten. It was a small text book on Physics by Balfour Stewart, Professor of Natural Philosophy at the University of Manchester, a position Ernest was later to hold.

In the preface to that book, Stewart states:
"The book has been written, not so much to give information, as to endeavour to discipline the mind by bringing it into immediate contact with Nature herself, for which purpose a series of simple experiments are described, leading up to the chief truths of each science, so that the power of observation in the pupils may be awakened and strengthened." One can only wonder at how much Ernest's life was influenced by this book.

When Ernest was 11 years old, his father having realised that the property was not producing an income necessary to cater for the family, he moved the family to Havelock to take up the job of flax milling (which was prosperous at the time). Today this is only a 108.2 km journey on the State Highway 6 but then the family had to endure several days of travel by boat, in the absence of any roads across the range of mountains separating the two areas. After a short time Ernest's father and Uncle set up their own flax mill, operating by the Ruapaka Stream. The Ruapaka Stream was too far to commute daily from Havelock, so Ernest's father, only returned to Havelock on Saturday night to be with the family, see the Saturday night entertainment in town and go to church on the Sunday.

At the beginning of January 1886 six boys, George Price (17), Charles Matthews (12), Freddy Matthews (5½) and three of Ernest's brothers, James, Herbert and Charles, set off in an open boat to sail to Hood's Bay about four miles away. On the return journey, while still a mile and a half from home, the boat capsized in a squall and both Herbert and Charles lost their lives. Their bodies were never found despite weeks of search of the coastline. Ernest was to have gone with them but had been sent to the flax mill to deliver something. Ernest was the person who had to give the terrible news to his mother when she was playing the piano to a group of girls who were around for tea. Martha never again played the piano and Ernest and his younger brother Jim were made to have swimming lessons until they could swim strongly.

The Rutherford family at Havelock, N.Z.: Left to right: Alice Rutherford, Mary Thompson (cousin), Arthur Rutherford (in front), Ernest Rutherford (behind), Eve Rutherford (in front, wearing white), James Rutherford (seated in chair) Nell Rutherford (standing behind), Ethel Rutherford (in front, wearing white), Flo Rutherford (seated in chair), George Rutherford (immediately behind), Herbert Rutherford (at rear), Martha Rutherford (standing side on), Charles Rutherford and Jim Rutherford. Photograph taken between 1883 and 1886 by William Collie.

Education

Ernest had been attending the Havelock primary school, where at the age of 15 he won an Education Board Scholarship, value £52/10/00 per annum, for two years, gaining a total of 580 marks out of a possible 600. It is said that the news of the scholarship came as he was picking potatoes in the fields and he immediately said "This is the last potato I shall ever pick" and at once went home.

He now went to Nelson College, where the excellent teaching he had had in primary school, saw him immediately placed in the fifth form where he continued to show his ability, winning four scholarships and then going on to win a University Entrance Scholarship in 1889, which took him to Canterbury College (founded 1873), where he commenced his University Course the following year, specialising in Mathematics and Physics. Compared with the numbers of students in these days, the classes were small and the teaching and student relationships were of a much more personal nature.

Here Ernest excelled and having gained his Pass degree in November 1892, he received a University Senior Scholarship to continue on for the Honours Degree, which he gained the following year. He was the second person in the University to gain a double first-class honours in Mathematics and Physics. He had also already turned his attention to physics research, in spite of the paucity of equipment available and continued his studies to gain a B.Sc. degree. In 1894 he was awarded a scholarship of £150 a year to study in a University of his choice. Ernest chose to go to the University in Cambridge, England, and moved there by October 1895.

Ernest was to remain here until 1898, gaining meanwhile a studentship in Trinity College for two years. His research was into the newly discovered X-rays. In August 1898 he was appointed Research Professor at McGill University, Montreal, where he sailed in September. He was to remain there until 1907 at an initial salary of £500 a year. Before leaving England he ordered uranium and thorium salts for experimenting in Canada.

Research work

In 1900 Ernest returned to New Zealand to marry Mary Georgina Newton on the 28th June, (April 1876 – 1945), only daughter of Arthur Charles and Mary de Renzy Newton, who lived in Christchurch, South Island. The pair had met in 1894 and though engaged to each other waited until Ernest was earning enough to keep them both. They were to have only one child, Eileen Mary, born in 1901 in Montreal, Canada, who later married the physicist Sir R.H. Fowler. Eileen died following the birth of her fourth child, Ruth, on the 23rd December 1930 and was buried in Ashmore, Dorset. Her other children were Peter Howard, b.1923, Elizabeth Rutherford (Taylor) b. 1925 and Eliot Patrick, b. 1927.

Rutherford's work on radioactivity was now receiving international acclaim and in 1906 he was awarded Honorary LL.D. degrees from the University of Pennsylvania and the University of Wisconsin, the first of many awards and honours. The following January he was appointed as the Professor of Physics at the University of Manchester, taking up the position in October and remaining there until 1919, when he made his final career move to Cambridge. In Manchester he began research on the newly discovered alpha particles and was awarded the 1908 Nobel Prize in Chemistry *"for his investigations into the disintegration of the elements, and the chemistry of radioactive substances"*. 1909 saw the reflection of a few alpha particles through a solid medium, leading to the famous gold-leaf experiment in 1911, which led to the nuclear atom mentioned at the beginning of this essay. During WW1 Ernest gave some time to the study of underwater acoustics to tackle the German U-Boat threat, being knighted for this in the 1914 Honour's List.

April 1919 saw Sir Ernest returning to Cambridge, as Professor of Physics and later Director of the Cavendish Laboratory there, holding the positions to his death in 1937. He was made a Member of the Order of Merit in 1925 and in the same year became President of the Royal Society. In 1930 he was elevated to the Peerage, taking the title of Baron of Nelson, New Zealand.

He coined the terms alpha ray, beta ray, gamma ray, and half-life for radioactive decay, and he was widely seen as the first scientist to split the atom. He published seven books, all on Radioactivity, and his chief recreations were golfing and motoring. He is known as the father of nuclear physics, even though his Nobel Prize was in Chemistry.

Taken ill suddenly in October 1937, Ernest died a week later in Cambridge on October 19, 1937. His ashes were buried in the nave of Westminster Abbey, just west of Sir Isaac Newton's tomb and by that of Lord Kelvin. In his honour the new element, number 104, was named Rutherfordium in 1997, after some controversy.
(https://en.wikipedia.org/wiki/Rutherfordium).

At his death aged 66, J. J. Thomson (then aged 80), his former teacher said:
"His work was so great that it cannot be compassed in a few words. His death is one of the greatest losses ever to occur to British science."

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Nelson Evening Mail, 12 January 1886, Page 2

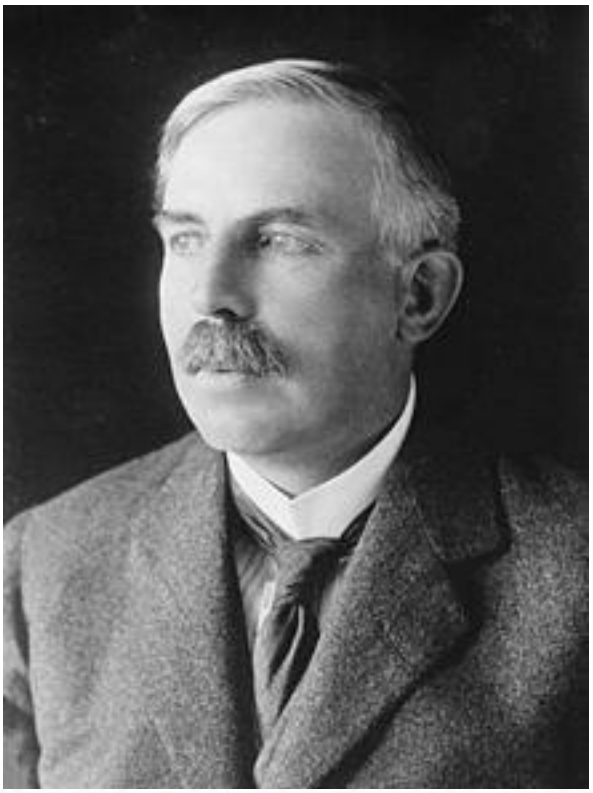
https://en.wikipedia.org/wiki/Ernest_Rutherford

□

"Ernest Rutherford's 1908 Nobel Prize in Chemistry wasn't given for the nuclear power station - he wouldn't have survived that long - it was given for showing how interesting atomic physics could be."

Andre Geim

Classic Chemical Quotes: #8
Ernest Rutherford (1871-1937)



"When we have found how the nucleus of atoms is built up we shall have found the greatest secret of all — except life. We shall have found the basis of everything — of the earth we walk on, of the air we breathe, of the sunshine, of our physical body itself, of everything in the world, however great or however small — except life."

Ernest Rutherford

Those Light Bulb Moments

(by courtesy of Alex Johnstone)

An appreciation by Bob Worley bobworley4@gmail.com

Chemistry is difficult to teach. You have frustrating moments when you want to hit your head against the wall and go home saying "Is it because of me, they don't understand?"

I picked up an old book of mine published 1977. One Chapter starts "You are perhaps puzzled why is a free energy change, rather than the enthalpy change, which is a measure of the ability of a reaction to do work." Wonderful! Here is an author sympathising with the student (and teacher) that our subject is hard. Thankfully, I am not alone.

Those words were written by Alex H. Johnstone and G Webb in the book, "*Energy, Chaos, and Chemical Change*". Nobody writes these types of books now. At 110 pages, aimed at the teacher and the 6th form to undergraduate level, it just not cost-effective for publishers. You would find this sort of material on the web nowadays. We dash things off in a couple of days (well some people do). I suspect this book took several months of care. It also requires careful, but provides rewarding, reading. The words are simple but the concept is deep. I often had (and still do) to go back to it because thermodynamics in chemistry is difficult.

I was at a meeting of 40 chemistry teachers, having been invited to do a microscale workshop, with Professor David Read. David asked the teachers *"How many of you have heard of Johnstone's triangle".* (My version is Figure 1 below.) David is modern, he has electronic measuring equipment and they had to press a button, so we saw the answer immediately. Only one teacher had heard of it. When he put the triangle on the board, you could see flashing light bulbs coming from 39 heads. In this simple diagram, Alex Johnstone encapsulated the issues of teaching chemistry.

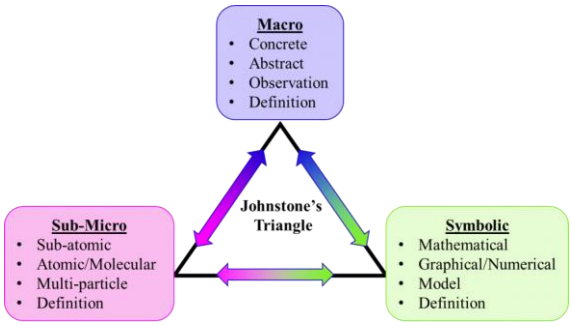


Figure 1: Johnstone's triangle

He knew the problems. Before entering Glasgow University, he had taught in a secondary school in Scotland for 13 years. He wrote a chemistry syllabus book in 5 volumes, called "*Chemistry Takes Shape*". This was published from 1964 onwards. I have copied out a small section of page 2 of the first volume. You can see his style all over it. In this section, he is teaching about small particles to the first year of Scottish High School Chemistry. Here are the macro events being interpreted at the nano-level from the very first student activities. The Bunsen Burner can wait!

1.1 A little goes a long way

You have met this idea before. It does not take much pepper to flavour a pot of soup or much cochineal to colour a bowl of cake icing. This who do not take sugar in tea can taste it if someone has put in even a small sprinkling.

Try this experiment to get some idea of how far a very little goes.

Place a crystal of potassium permanganate in a large bowl or fish tank and ass a little water to dissolve it. Now keep adding water and stirring until the purple colour becomes pink and eventually disappears.

A little goes a long way!

The crystals may have spread itself though water more than 1 million times its own volume!

What has been happening to that crystal as it dissolves? Some people have suggested that (i) it has somehow stretched itself out like very stretchy rubber getting thinner in the process or (ii) it has broken down

(See Appendix for a version you can try).

He also produced a textbook called *Chemistry About Us*, (Heinemann) in 1988. He said: *"We were also lucky to publish at a time when the curriculum had not been set in concrete. Teachers were open to ideas. Now there is a real pressure for textbook writers to conform to the set concrete pattern of the "accepted" curriculum. Woe betide anyone who is too adventurous. His sales are doomed."* He was so right.

The triangle was my first light bulb moment from Alex Johnstone but there were more. If you put Alex H. Johnstone into Google, you will find many papers written by him and his students over the last 30+ years (https://www.researchgate.net/profile/Alex_Johnstone) .
I know of many teachers at the present time are much exercised by overload of working memory during teaching. Alex Johnstone was there in 1984 (http://pubs.acs.org/doi/abs/10.1021/ed061p847) .

Amongst other issues, he remarks on the amount of "noise" in teaching, which distracts the student from learning. Sometimes, it is coping with a series of complex instructions while trying to deal with a pipette filler.

Alex died before Christmas 2017 at the age of 88. I never met him but I feel I knew him ever since I read about him in the 70 and 80s. This occurred because I tried to gain more CPD in my subject.
Of course people like to extend the triangle to a tetrahedron. Peter Mahaffy calls the fourth point the "human element" (http://pubs.acs.org/doi/pdfplus/10.1021/ed083p49).

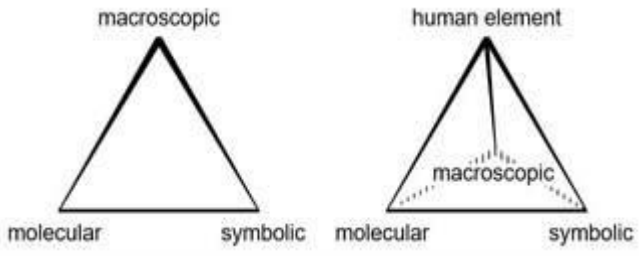


Figure 2: The triangle extended to a tetrahedron

We are using the word "elements" in a non-chemical context in an essay about education in chemistry. I think Alex would not approve of the word (as it would cause "noise") but approve of the extension. He wrote at the beginning of Chapter 13 of *"Energy, Chaos, and Chemical Change"*, which is entitled "Thermodynamics and Every Things", *"The work in this book will remain largely an academic exercise unless we can see it operating in the world at large."*

Perhaps the word to use is "Relevance".

Here is Alex writing about syllabus order.

Alex Johnstone on syllabus order
Begin where the students are. From an information processing point of view, begin with things that they will perceive as interesting and familiar so that there are already anchorages in their long term memory on which to attach the new knowledge. Do we begin in the traditional way with salt, sodium carbonate, silver nitrate and barium chloride OR do we begin with petrol, camping gas, plastics and foods? Organic chemistry has traditionally been thought of as too difficult for beginners, but a moment's thought will show that it is not necessarily so. We are beginning with the macro and can afford to take in some submicro. Students will accept that hydrogen forms one bond, oxygen two, nitrogen three and carbon four. With this simple idea, you can go a long way. Both corners of the triangle are visualisable and can be made concrete with models. From this, simple formulae arise because students can count the 'atoms'. There is no need for multipliers and awkward brackets (as in a compound like $Pb(NO_3)_2$). With only these simple submicro and representational ideas you can go a long way through hydrocarbons, alcohols, aldehydes, ketones, esters, carbohydrates, fats, proteins and plastics. Only when we meet carboxylic acids do we need to think about any change in bonding

Of course, any attempt at doing this in England was defeated by the introduction of a KS3 syllabus and exams for 14 year olds (gone, thank goodness!). There still appears a mentality, amongst teachers, that KS3 is still rigidly there even though the exam is now only for 16 year olds. Does anyone teach organic chemistry to 11 and 13 year olds? In the Book *Chemistry About Us*, (aimed at the 14-16 year students), he goes straight into covalent bonding and organic chemistry. Ions come later and pH appears three quarters of the way through, because

although it appears straight forward, it is a log scale and that now is not taught in some maths syllabuses.

In this article (http://pubs.acs.org/doi/abs/10.1021/ed077p1571) you will find Alex's 10 commandments of teaching. The 10th is *"There should be opportunity given to teach (you don't really learn until you teach)*". Those not in teaching (especially writers in and to the tabloid press) have the mistaken idea that teachers enter school with all the correct skills to teach and demonstrate practical skills immediately.

Ten Educational Commandments

1. What is learned is controlled by what you already know and understand.
2. How you learn is controlled by how you learned in the past (related to learning style but also to your interpretation of the "rules").
3. If learning is to be meaningful, it has to link on to existing knowledge and skills, enriching both (*3*).
4. The amount of material to be processed in unit time is limited (*4*).
5. Feedback and reassurance are necessary for comfortable learning, and assessment should be humane.
6. Cognisance should be taken of learning styles and motivation.
7. Students should consolidate their learning by asking themselves about what goes on in their own heads—metacognition.
8. There should be room for problem solving in its fullest sense (*5*).
9. There should be room to create, defend, try out, hypothesise.
10. There should be opportunity given to teach (you don't really learn until you teach) (*6*).

Teachers are constantly in need of subject and pedagogical CPD and this is at the present being denied. Do notice how wonderfully straightforward his language is. He does not try to wrap up sentences in words which non-researchers would not understand immediately to make the articles appear learned. Remember, to a chemist, "meta" means the third position on the benzene ring; "elements" are our basic building blocks; scaffold is a collection of steel bars with clamps. Just as the student has difficulty in understanding words which have dual (or more) meanings in chemistry and everyday life, so the chemistry teacher has issues with words in psychology, which have other meanings in chemistry.

In a tweet David Read summed Alex's contribution beautifully as *"How much of our teaching, and how many of our conversations have been influenced by this giant of Chem Ed? Future generations of Chem Ed practitioners will be influenced by him for decades to come."*

□

From the Editor:

Tina Overton remembered Alex Johnstone in *Education in Chemistry* (https://eic.rsc.org/news/alex-johnstone-19302017/3008447.article). She said this about Alex:

"Alex had a long career in secondary and tertiary chemistry education, but for me and my peers it was his work in chemistry education research that was so influential. He demonstrated how scientists could make the transition to pedagogic research. He adopted research designs that made sense to scientists and used language that made his findings accessible. In particular, he made cognitive load theory and the information processing model relevant to the education of science undergraduates. Today, discussion of these issues in chemistry is still informed by his papers."

His two sons, Alan and David, wrote an appreciation in *The Scotsman*, which is worth reading. They give a different perspective on Alex the man and father.

"Outside his work, Alex possessed many interests. These included his skills in French and German, his love of walking and climbing, together with his interests in history, botany and geology. He shared his wider interests with many a student group. He loved choral singing and was also a lay-preacher in his local church, his earlier Biblical training at Edinburgh University being brought into use.

He was a brilliant, inspirational teacher, with a deep empathy for the learner, especially the struggling learner. He brought these skills into his teaching with Christian groups and large numbers benefited from the incisive clarity of his insights and his deep sense of spiritual reality and academic rigour."

(https://www.scotsman.com/news/obituaries/obituary-prof-alex-johnstone-academic-and-author-in-chemistry-1-4642975)

Appendix

Students can quite easily do this and with the CLEAPSS conductivity indicator there is a bonus for progression in later years.

- Put 10 mL of cold tap water into a plastic Petri dish.
- Wet the end of a wooden tooth pick in the water, dip the piece tooth pick into a small quantity of potassium manganate(VII) (permanganate) so that a little adheres to the end.
- Place the end in the centre of the dish so the solid comes off the stick.

The first picture below shows the purple colour spreading out by dissolving and diffusion.

- What happens with hot water from a kettle?

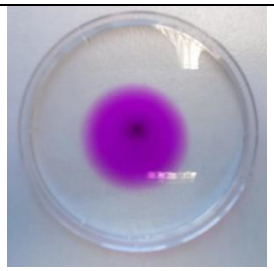
Close your eyes and visualise what has happened to that tiny crystal when colouring the water.

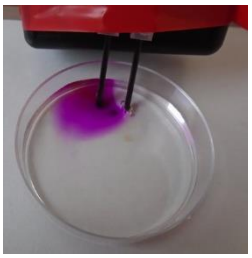
Can you begin to put some numbers into this experiment? Stir the solution so it is a uniform colour. I would estimate that that crystal has a mass or less than 0.001g. Yet you can see the colour in 10 mL of water.

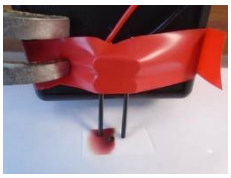
- Into a second Petri dish, add 9 mL of water from a measuring cylinder and 1 mL of coloured solution from the first Petri dish, stir gently and decide if the colour can still be seen.

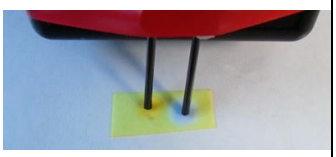
So now there is less than 0.0001g of the purple solid in 10 mL of liquid. Can it be done again? Can you see it the colour better from another position than from the top? How far can you go with this technique with a 3rd or 4th Petri dish?

Now to show how you can progress the procedure as students become older and you spiral the curriculum. The second picture shows how a direct electric current distorts the spreading out with the colour moving to the positive electrode so that the purple colour must have a negative charge. This can even be carried out on filter paper dampened with tap (or salt) water. The final picture shows paper with a drop of a mixture of 1 drop of 0.1M potassium chromate, 1 drop of 0.1M copper sulfate in 5 drops of 2M ammonia. The negative chromate ions migrate to the positive electrode and positive copper ions move to the negative electrode. Alex thought the concept of ions, and formulae, was so difficult in the early stages of learning chemistry that one should always start with organic chemistry, which dealt mainly with atoms and molecules and lots of molecular shapes.









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Heinemann Educational Books (1964). There are 5 volumes and Teacher's books as well.

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ChemLingo: Eponymous laws and units

Peter E. Childs

Eponymous means that something is named after a person. Science is full of laws, units, equipment and effects named after their discoverers. John Dalton (1766-1844) is famous for establishing the modern theory of atoms on an experimental basis. He has given his name to a unit of atomic or molecular mass, the Dalton, Da. He was also known for his red-green colour blindness, which he studied in himself, and this type of hereditary colour blindness, very common in men, is known as daltonism. In many ways Dalton was a scientific polymath and his initial work was in the study of gases and gas mixtures, where he arrived at Dalton's law of partial pressure. How many other scientists have a unit and a law named after them?

Quite a few people as it turns out. Michael Faraday has a number of things named after him, which is an indication of his scientific importance: he has Faraday's Laws (of electrolysis and of induction), the units the Faraday and the Farad, as well as the Faraday effect and the Faraday cage. Charles Augustin de Coulomb has the Coulomb and Coulomb's law. James Prescott Joule has the Joule and Joule's laws. Jean Marie Luis Poiseuille gave us the Poise (unit of viscosity) and Poiseuille's law.

However, the name can mislead and while Henry's law is due to William Henry, a Manchester brewer and chemist, the Henry unit of inductance we owe to the American physicist Joseph Henry. Isaac Newton gave us the Newton, N and Newton's laws of motion. Louis Pasteur gave us the Pasteur pipette and pasteurisation. Max Planck gave us Planck's constant and Planck's law. Amadeus Avogadro bequeathed us Avogadro's constant (a number known to all chemists) and Avogadro's law. Pierre and Marie Curie between them have the curie, the Curie Point and curium.

Having a law, a unit, a piece of apparatus is both a claim to fame and a way of ensuring one's name lives on for posterity. Today in the chemistry laboratory we use Bunsen burners, Liebig condensers, Erlenmeyer flasks, Büchner flasks and funnels, and in my day we used the Kipp's apparatus to make gases. How many pieces of laboratory equipment can you find named after people and who were they named after?

This website gives several lists of named things.
http://www.careerchem.com/NAMED/Homepage.html
For a list of scientific laws named after people see:
https://en.wikipedia.org/wiki/List_of_scientific_laws_named_after_people

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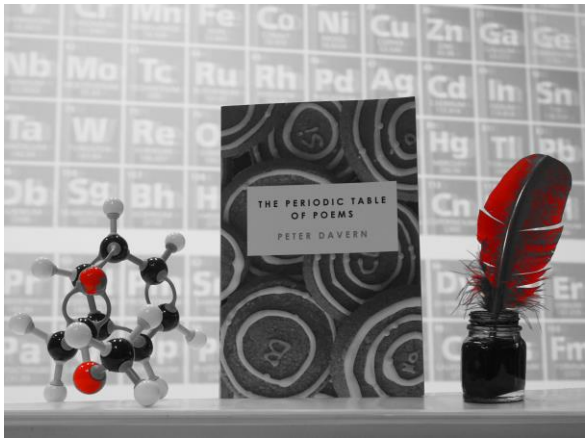
Elementary chemistry

Periodic Poems



"The Periodic Table of Poems" is a new paperback book by Peter Davern, a lecturer in the Department of Chemical Sciences at the University of Limerick. The product of almost five years of background research, it contains a collection of 93 short poems written to celebrate the chemical elements that make up our universe. Each poem explores the properties of a different element and is accompanied by a set of explanatory notes; these notes, in turn, are complemented in many instances by a playful, hand-drawn illustration that further emphasises a particular fact about the element in question. Few, if any, books on the periodic table of the elements have treated their subject in this way, making "The Periodic Table of Poems" quite a unique and significant body of work. Small wonder then that the book's back cover contains the following affirmative endorsement from Dr Eric Scerri, an internationally recognised authority on the history and philosophy of the periodic table: *"Peter Davern's new book is full of delightful poems about many of the chemical elements that inhabit the periodic table. In addition the accompanying text makes meaningful references to the properties of the elements and their compounds and will be of interest to chemistry students as well as their instructors."*

"The Periodic Table of Poems" (ISBN-10: 1978415079, ISBN-13: 978-1978415072, 260 pages) is published by CreateSpace Independent Publishing Platform, 2017. It is available on Amazon.co.uk, retail price: £ 9.80.

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N.B. The first five of these poems were published in past issues of *Chemistry in Action!*

Pb Lead paint is still a problem

(*The Economist* 24/2/18)
Lead poisoning is still a major problem despite the recognition for many years that lead is a neurotoxin. Lead has been banend in paint (1950s onwards) and in petrol (1970s onwards) in many developed countries, but not worldwide. So why is it still a problem when we know the efects and we understand the science? Half a million American children have lead in blood beyond 5µg/dL. Most of the exposure comes from old lead-based paints found in old buildings, which flakes off and creates dust, which are ingested by children. In developing countires lead-based paint is still being made and sold. A blood lead level of 10 µg/dL lowers the IQ of young children by 6 points, equivalent to one year of schooling. Lead water pipes are also a problem in towns, including Ireland, as they can corrode and release lead into the water. pH is a crucial factor as low pH (acidic) dissolves lead. Also lead dissolves more in soft water than in hard water.
https://www.water.ie/water-supply/water-quality/lead-in-drinking-water/

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Cl Chlorinated oragnics in nature

(*C&EN* 23/10/17 p. 15-17)
Chlorine compounds, especially organochlorines, have a bad name for toxicity and carcinogenicity and are classed as persistent organic pollutants. Most organic solvents containing chlorine are banned in education and in industry. Chlorine has in the past been described as 'the devil's element', because of its use as a posion gas in WWI (still being used in Syria) and its poisonous compounds such as PCBs. But chlorine in many chemical forms is ubiquitous in the environment and in living things, in organic and inorganic forms. We need ~6g of NaCl per day in our diet (though too much is

harmful, so is too little), and our stomachs contain hydrochloric acid for digestion. The oceans are full of salt (sodium choride), as well as bromine and iodine compounds, and not surprisningly the halogens are incorporated into natural products. Researchers continue to find chlorine compounds in nature, often highly toxic, which have never been made or used by industry. Just finding organochlorines doesn't mean they are a result of manmade pollution. Naturally-occurring organochlorine compounds contain radioactive carbon-14 from the atmosphere; synthetic ones made from oil do not contain carbon-14. This enables scientists to identify the source of organohalogen compounds found in nature. The natural compounds, just like the synthetic ones, can bioaccumulate in food webs and can be toxic. Indeed it is thought that some species synthesise toxic organohalogens for defensive purposes, for chemical warfare. In some cases natural compounds outweigh synthetic ones: 10,000 t of chloromethane are produced by industry but **3.5 million t** are produced naturally! Marine sponges can contain up to 10% of dry weight of polybrominated compounds. Some seaweeds are rich in iodine.

It is a reminder to us that pollutants (chemicals which are harmful) can be natural in origin and are not just manmade. Natural does not mean non-toxic or safe or non-carcinogenic. Given how abundant chlorine is in the environment it is not surprising that it becomes incoorporated in living things, in a wide variety if chemical compounds. At present over **6,000** natural organohalogen compounds are known.
"Nature was making chemical deterrents to predators way before Monsanto, Dow and other companies began making organohalogen pesticides." Chris Reddy

Some microbes have also leanred how to break down organohalogen pollutants into less toxic forms.

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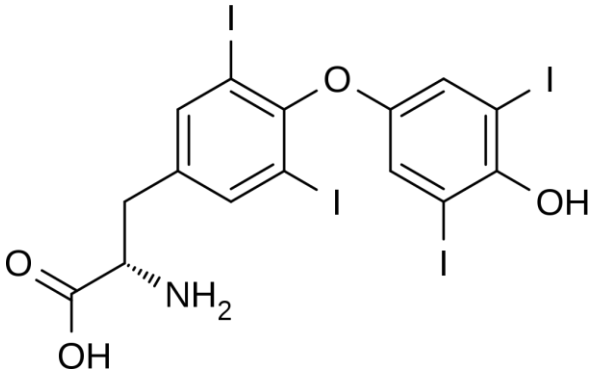
Iodine in our diet

We need iodine in our diet to synthesise the typroid hormones. The sturcture of one of them, S-thyroxine, is shown below. Note that there are 4 iodine atoms per molecule.



In Ireland most of our iodine comes from cow's milk, so people who don't drink milk may be iodine deficient. In fact, Irish famers have been so successful in tackling iodine deficient that some Irish milk contains too much iodine for the EU market!

Food	Serving Size	Iodine
Dried Seaweed (Buy from Amazon.com)	1 gram	16-2984µg (11% - 1989% DV)
Cod	3 ounces*	99µg (66% DV)
Iodized Salt **(Fortified)**	1 gram	77µg (51% DV)
Baked Potato with peel	1 medium	60µg (40% DV)
Milk	1 cup (8 fluid ounces)	56µg (37% DV)
Shrimp	3 ounces	35µg (23% DV)
Fish sticks	2 fish sticks	35µg (23% DV)
Turkey breast, baked	3 ounces	34µg (23% DV)
Navy beans, cooked	1/2 cup	32µg (21% DV)
Tuna, canned in oil	3 ounces (1/2 can)	17µg (11% DV)
Egg, boiled	1 large	12µg (8% DV)

In many countries iodine deficiency is dealt with by the provision of iodised salt, but this is rarely available in Ireland and the UK. Good luck in some finding some in your supermarket! Iodine intake is

especially important in pregnant women. Seafood, seaweed, baked potatoes are good sources of iodine, as well as turkey, strawberries and cranberries. You can overdose on iodine but under-dosing is more of a problem.

In the United States, the recommended daily allowances (RDA) for iodine intake are 150 µg in adults, 220–250 µg in pregnant women, and 250–290 µg in breastfeeding women.

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Co Cobalt: a conflict metal with a crucial role

In the last issue (#110) we looked at lithium a key metal for the future because of its role in batteries for electric vehicles and consumer equipment. However, 'lithium' batteries also require cobalt to function and cobalt is in shorter supply than lithium, and over 50% comes from the Democratic Republic of Congo (DRC). The DRC has been plagued by wars, political instability, and the source of some of the cobalt is debatable, with the use of child and slave labour, and the profits being used to fund fighting. Not a good idea to have most of your essential eggs in a bloodstained basket. Also most of the crude ore is shipped to China for refining, so that China also has a controlling influence on cobalt supply. The increased demand for cobalt has resulted in prices tripling in two years. An 85 Wh battery used by Tesla requires some 8 kilograms (17.6 pounds) of cobalt. All car manufacturers are planning to increase production of electric cars and will eventually stop producing petrol and diesel cars. By 2040 this is expected to drive up cobalt demand by 9,300%. Carmakers and computer manufacturers like Apple have been trying to line up long-term contracts for cobalt.

Table 1: World Mine Production and Reserves (https://minerals.usgs.gov/minerals/pubs/commodity/cobalt/mcs-2018-cobal.pdf)

	Mine production	
	2016	2017[e]
United States	690	650
Australia	5,500	5,000
Canada	4,250	4,300
Congo (Kinshasa)	64,000	64,000
Cuba	4,200	4,200
Madagascar	3,800	3,800
New Caledonia[9]	3,390	2,800
Papua New Guinea	[7]2,190	3,200
Philippines	4,100	4,000
Russia	5,500	5,600
South Africa	2,300	2,500
Zambia	3,000	2,900
Other countries	7,600	5,900
World total (rounded)	111,000	110,000

Very little cobalt is mined on its own. The vast majority is a by-product of copper and nickel mining. It is clear from the table below that Congo dominates mine production, producing 13 times more than its nearest competitor.

One of cobalt's most spectacular uses is to produce blue glass (cobalt blue) (Figure 1).

Figure 1: Some glass vessels coloured with cobalt (https://en.wikipedia.org/wiki/Cobalt#/media/File:Bristol.blue.glass.arp.750pix.jpg)

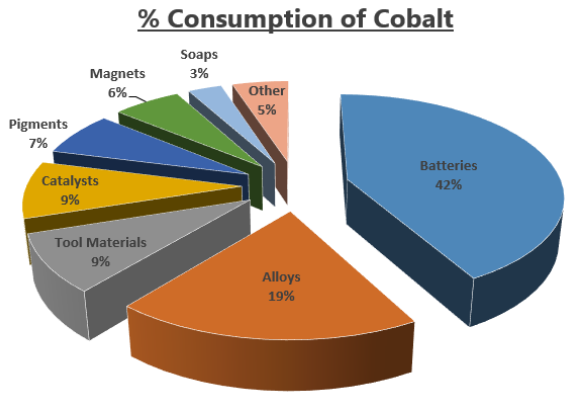

Figure 2: End-uses of cobalt are dominated by batteries (https://rivaresources.com.au/cobalt-background-information/

Cobalt is important for many things but batteries (see Figure 2) already dominate its use (42%), and this will increase in future. Cobalt-lithium batteries have the highest energy densities and make up over 75% of lithium batteries.

Cobalt is important in metal alloys, used for making turbine blades and cutting tools, and in making permanent magnets. It is an important trace element in our diet as it lies at the heart of vitamin B-12, cobalamin, which is needed for red blood cell formation. It is not made in the body and must be obtained from food, particularly meat, so vegetarians may need to take supplements.

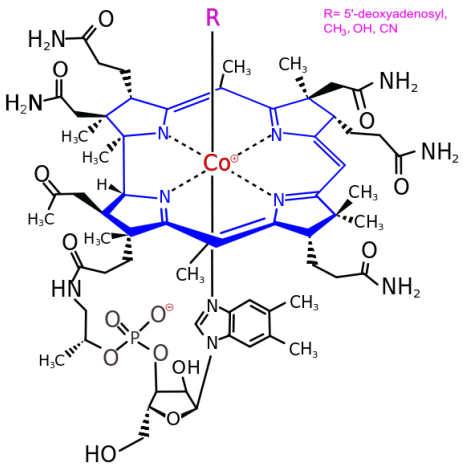

Figure 3: The structure of cobalamin, vitamin B-12 (https://commons.wikimedia.org/wiki/File:B12_Cobalamin.svg)

Cobalt is one of those essential elements which we need in small amounts, or we suffer from deficiency, but in large amounts can be toxic. You may remember that cobalt(II) chloride paper was banned for use in Irish schools because cobalt(II) salts are toxic and carcinogenic. However, the LD_{50} values of soluble cobalt salts has been estimated to be between 150 and 500 mg/kg. Thus, for a 100 kg person the LD_{50} would be about 20 grams. You would have to eat an awful lot of cobalt chloride paper to be poisoned. It is also identified as possible carcinogen but it is hard to see that cobalt chloride paper, used rarely, can be much of a risk. The indicating silica gel also contains cobalt chloride to indicate its moisture content.

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International year of the Periodic Table 2019 (IYPT 2019)

On 20 December 2017, during its 74th Plenary Meeting, the United Nations (UN) General Assembly 72nd Session has proclaimed 2019 as the International Year of the Periodic Table of Chemical Elements (IYPT 2019). In proclaiming an International Year focusing on the Periodic Table of Chemical Elements and its applications, the United Nations has recognized the importance of raising global awareness of how chemistry promotes sustainable development and provides solutions to global challenges in energy, education, agriculture and health. Indeed, the resolution was adopted as part of a more general Agenda item on Science and technology for development. This International Year will bring together many different stakeholders including UNESCO, scientific societies and unions, educational and research institutions, technology platforms, non-profit organizations and private sector partners to promote and celebrate the significance of the Periodic Table of Elements and its applications to society during 2019.
https://iupac.org/blog/2017/12/28/united-nations-proclaims-international-year-periodic-table-chemical-elements/

Motivation:
The Periodic Table of Chemical Elements is one of the most significant achievements in science, capturing the essence not only of chemistry but also of physics and biology. It is a unique tool, enabling scientists to predict the appearance and properties of matter on Earth and in the rest of the Universe. Great Russian scientist Dmitry Mendeleev is regarded as the father of the Periodic Table. By 1860, only 60 elements had been discovered (we now know 118) and indeed some of the information about these 60 was wrong. It was as if Mendeleev was doing a jigsaw with one third of the pieces missing, and other pieces bent! Mendeleev had written the properties of elements on pieces of

card, and tradition has it that after organizing the cards while playing patience, he suddenly realized that, by arranging the element cards in order of increasing atomic weight, certain types of element regularly occurred. The greatness of Mendeleev was that not only did he leave spaces for elements that were not yet discovered but he predicted properties of five of these missing-elements and their compounds. Three of these missing elements were discovered, by others within 15 years (i.e. within his lifetime). 1869 is considered as the year of discovery of the Periodic System by Dmitry Mendeleev. 2019 will be the 150th anniversary of the Periodic Table of Chemical Elements! The International Year of the Periodic Table of Chemical Elements will be a worldwide initiative to highlight the importance of the Periodic Table in science, technology, and sustainable development of humankind.

The passage above is taken from an excellent booklet on the IYPT and I would recommend you downloading this and using it in school. http://iupac.org/cms/wp-content/uploads/2017/12/IYPT-Prospectus_20171209.pdf

Events 2019

The preliminary international programme includes the following events and it is intended that many others will be added across the globe as 2019 approaches.

• The opening ceremony for the International Year of the Periodic Table of Chemical Elements is planned for February, 2019

• Special Symposium during IUPAC 2019, Paris: The Periodic Table at 150 • 51st International Chemistry Olympiad, July 2019

• Mendeleev International Chemistry Olympiad, April, 2019

• Markovnikov Congress (150 Anniversary of Markovnikov's rule), June 2019

• EuCheMs Inorganic Chemistry conference EICC-5, June 2019

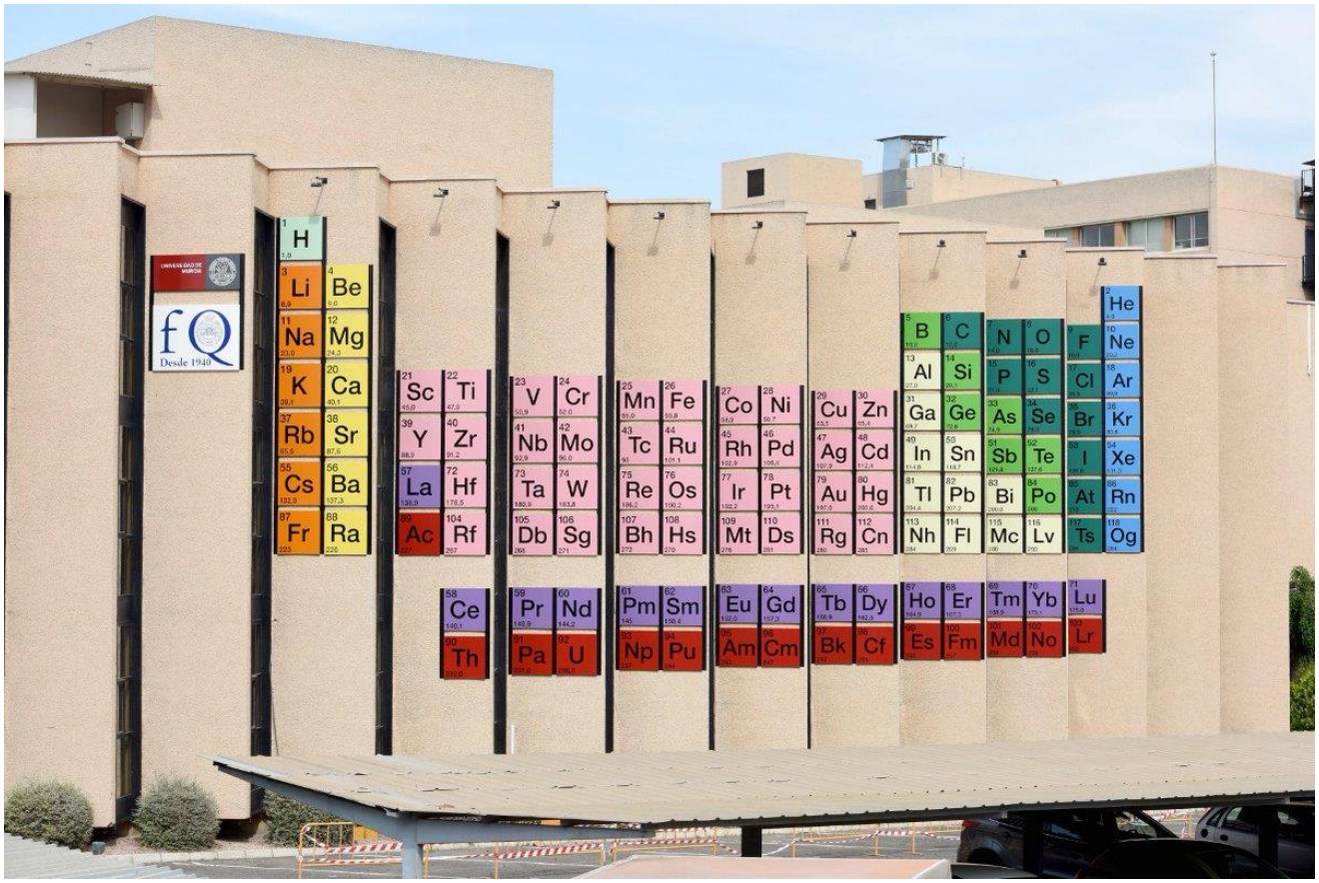
• Celebration of the 150th anniversary of Mendeleev Table of Chemical Elements during the 47th World Chemistry Congress

• The jubilee Mendeleev Congress on General and Applied Chemistry related to the International Year of the Periodic Table

In Ireland the affiliated body to IUPAC is the Royal Irish Academy, but I would hope that all the relevant bodies – ISTA and Institute of Chemistry of Ireland, and the Irish sections of the RSC and SCI – would all collaborate to mark this year and promote chemistry. It follows on from the International year of Chemistry 2011 and the International Year of Crystallography 2014.

Do you have any ideas for marking IYPT 2019 in your school? There's lots of things you could do – send in your ideas to me and when they happen in 2019 send in reports and photos. We will put some ideas in the enxt issue of Chemistry in Action! (#112, Autumn 2018).

Could you produce a giant Periodic Table in your school – on a wall, in the school yard?



The Chemistry Department of the University of Murcia in Spain has put a giant Periodic Table on its building (see above).

What a brilliant idea!
PEC

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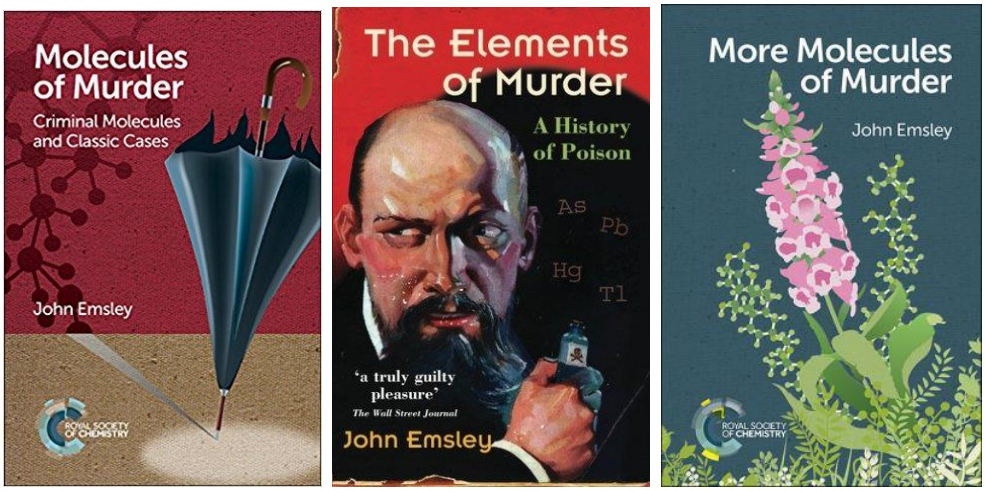
The Periodic Table Taxi

For your bookshelf:

Here are some popular chemistry books you might find sources of interesting anecdotes to enliven your lessons with.

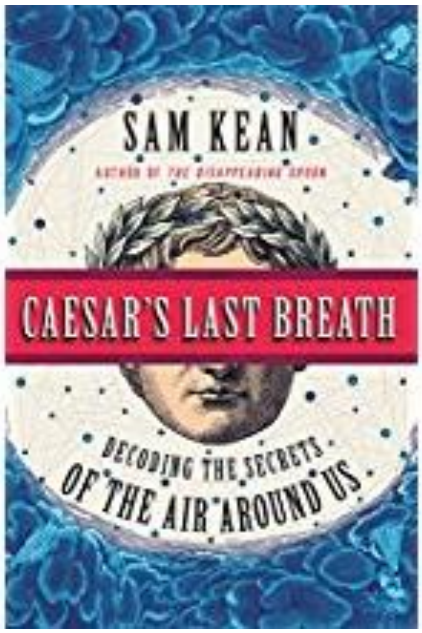
More Molecules of Murder. John Emsley (RSC, 2017)



Not content with his earlier books, *The Elements of Murder* (OUP, 2006) *Molecules of Murder* (RSC, 2008), John Emsley has done it again with a book on *More Molecules of Murder* (RSC, 2017). He is one of the few popular science writers who writes about Chemistry and he gave an excellent lecture some years back at a ChemEd-Ireland conference.

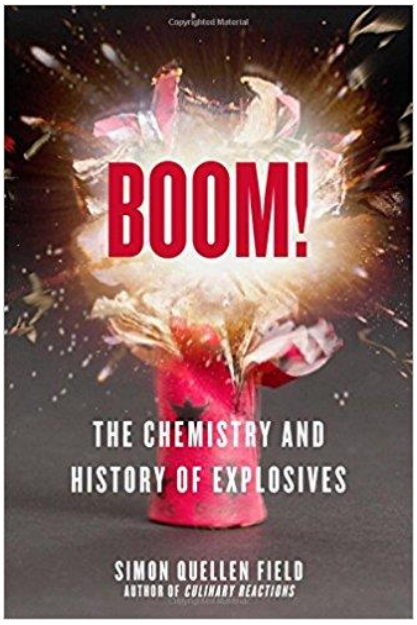
Caesar's Last Breath. Decoding the secrets of the air around us.

Sam Kean
(Little, Brown amd Company, 2017)



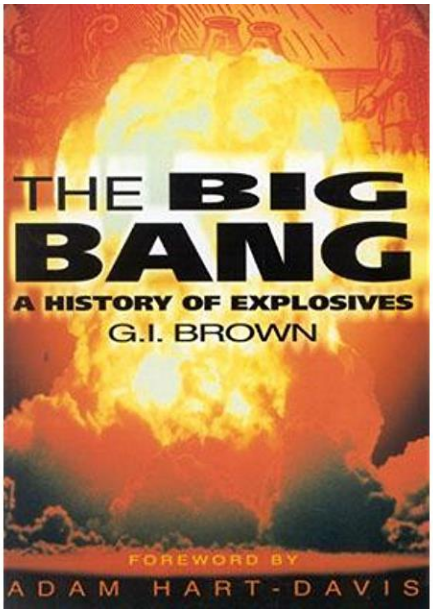
Boom!

Simon Quellen Field
(Chicago Review Press, 2017)



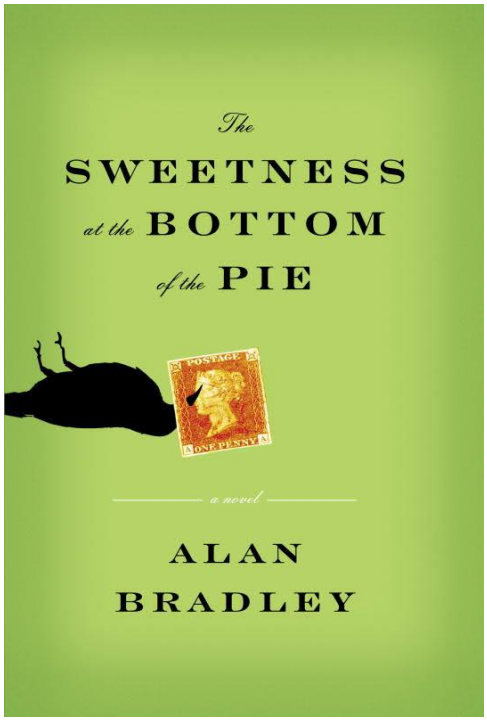
The title says it all. There is no shortage of books on this topic and one might need to be careful reading it on public transport. In 1998 G. I. Brown,

a retired chemistry teacher, wrote the book *The Big Bang: A History of Explosives*, which you may be able to get second-hand.



Cheapest place to buy these books in Ireland is through the Book Depository – discount plus free postage.

The sweetness at the bottom of the pie
Alan Bradley



This book introduces a new, fictional chemical heroine from Canadian author Alan Bradley: Flavia de Luce. If you teach girls or have a daughter you might want to introduce them to Flavia, who loves chemistry and has her own laboratory, inherited from her uncle. She solves mysteries and creates mayhem. This is the first in a series of 9 novels, soon to be a TV series, with unusual titles. The books might be a good way to hook girls into chemistry.
A couple of quotes from Flavia:

"As I stood outside in Cow Lane, it occurred to me that Heaven must be a place where the library is open twenty-four hours a day, seven days a week. No ... eight days a week."

"If there is a thing I truly despise, it is being addressed as "dearie." When I write my magnum opus, A Treatise Upon All Poison, and come to "Cyanide," I am going to put under "Uses" the phrase "Particularly efficacious in the cure of those who call one 'Dearie."
Alan Bradley, ***The Sweetness at the Bottom of the Pie***

Flavia de Luce Book Series

- # 1 The Sweetness at the Bottom of the Pie.
- #2 The Weed That Strings the Hangman's Bag.
- #3 A Red Herring Without Mustard.
- #4. I Am Half-Sick of Shadows.
- #5. Speaking from Among the Bones.
- #6. The Dead in Their Vaulted Arches.
- #7. As Chimney Sweepers Come to Dust.
- #8. Thrice the Brinded Cat Hath Mew'd.
- #9 The Grave's a Fine and Private Place.

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Send one hardcopy + diagrams and a copy on disc (or by email as a Word document) when submitting material.
You can contact the editor by email at: **peter.childs@ul.ie**

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Chemistry in Action! is in the process of being put on the Internet at URL:
www.cheminaction.com

The magazine is now being distributed mainly in an electronic format. The current issue and a number of back issues are available. A limited number of hard copies are being printed and if you would like a hard copy (subject to availability) at a cost of €5 per copy, contact peter.childs@ul.ie

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